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Developing Robust Support Structures for High-Technology Subsystems

The AH-64 Apache Helicopter

Marc L. Robbins, Morton B. Berman,
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RAND

ARROYO CENTER

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PREFACE

This is the third in a series of reports investigating the influence of alternative logistics structures on the combat capability of high-technology weapon systems.[1] The report, sponsored by the Readiness and Sustainability Program of the Arroyo Center, continues the study of using a new methodology to identify and evaluate alternative logistics structures for high-technology subsystems used by major U.S. Army weapon systems. Earlier work investigated alternative means of supporting the high-technology subsystems of the M-1 Abrams tank and the M-2/3 Bradley fighting vehicle. This report extends and expands on that work by considering the even more demanding support needs of the mission equipment package of the AH-64 Apache attack helicopter. It documents final results of research first distributed to the Army in March 1989.

This research's primary goal is to demonstrate the influence of alternative logistics structures on the war-fighting capabilities of combat units. A secondary goal is to provide a model analysis employing new techniques that might guide U.S. Army analysts in similar future evaluations. Ultimately, the research goal is not only to support future weapon systems but to inform logistics policy and technical decisions the Army is considering.

The Arroyo Center suggested this research topic to the Army because the introduction of sophisticated electronic systems in Army armor and aviation weapon systems threatens to complicate logistics support the same way it has for the Air Force. The concepts, tools, and techniques developed by RAND's Project AIR FORCE over the past decade should prove useful to the U.S. Army. This research provided the vehicle to test these concepts, tools, and techniques in an Army setting.

This study seeks to extract general policy conclusions for the support of high technology in the Army by performing a historical data analy-

[1]See M. B. Berman, D. W. McIver, M. L. Robbins, and J. Schank, *Evaluating the Combat Payoff of Alternative Logistics Structures for High-Technology Subsystems*, RAND, R-3673-A, October 1988; and William Wild, *Supporting Combined-Arms Combat Capability with Shared Electronic Maintenance Facilities*, RAND, R-3793-A, May 1990.

sis of the AH-64 Apache. In the course of analysis and publication of these results, many of the individual issues affecting the Apache itself have been dealt with and resolved. This study's value has less to do with "fixing the Apache" than with guiding the Army in making policy choices in supporting high technology as a whole now and in the future.

This research project, "Improving Combat Capability Through Alternative Support Structures," was sponsored by the Training and Doctrine Command (TRADOC) Combined Arms Support Command (CASCOM). The research should be of interest throughout the Army logistics community.

THE ARROYO CENTER

The Arroyo Center is the U.S. Army's federally funded research and development center for studies and analysis operated by RAND. The Arroyo Center provides the Army with objective, independent analytic research on major policy and management concerns, emphasizing mid- and long-term problems. Its research is carried out in five programs: Policy and Strategy; Force Development and Employment; Readiness and Sustainability; Manpower, Training, and Personnel; and Applied Technology.

Army Regulation 5-21 contains basic policy for the conduct of the Arroyo Center. The Army provides continuing guidance and oversight through the Arroyo Center Policy Committee, which is cochaired by the Vice Chief of Staff and by the Assistant Secretary for Research, Development, and Acquisition. Arroyo Center work is performed under contract MDA903-91-C-006.

The Arroyo Center is housed in RAND's Army Research Division. RAND is a private, nonprofit institution that conducts analytic research on a wide range of public policy matters affecting the nation's security and welfare.

SUMMARY

BACKGROUND

The U.S. Army is relying more and more on high-technology weapons systems, which present a challenge for the logistics structure that must support them. Unlike the simpler weapons systems of the past, today's technologically sophisticated systems have components that are extremely expensive; in addition, maintaining today's systems is far more difficult, because diagnosing and repairing complex subsystem faults require sophisticated and expensive test and diagnostic equipment. And on top of all this, the uncertainties of war make forecasting demands for these expensive items highly problematic. These factors combine in ways that negate the value of preplanned inventory as a way to solve the demands for spares in changing environments.

We believe that a more realistic solution to this challenge involves developing and evaluating alternative logistics structures whose more fungible resources—like transportation and repair—are used to respond to changing wartime demands.

OBJECTIVE

Using data on the high-technology subystems of the AH-64 Apache attack helicopter, we hypothesize alternative logistics structures and assess their responsiveness—in terms of cost-effective improvements to weapon system availability—under contingency scenarios.

SUPPORTING HIGH-TECHNOLOGY IN THE AH-64 APACHE

By virtue of its mission equipment package (MEP), which includes such major high-technology subsystems as the Target Acquisition Designation Sight/Pilot Night Vision Sensor (TADS/PNVS), the Fire Control Computer (FCC), and the Integrated Helmet and Display Sight System (IHADSS), the Apache is the most advanced and lethal attack helicopter in the world.

This advanced capability does not come cheaply. Overall, the high-technology slice of the Apache costs proportionately far more than it does in other major Army weapon systems. In addition, these high-

technology components constitute a disproportionate share of the repair workload; although they represent only 25 percent of the total line replaceable units (LRUs), they account for about 50 percent of all removals, and 75 percent of removals weighted by dollar value.

Not only are the high-technology portions of the Apache a relatively large part of the workload, they also present serious maintenance problems. Apache repairs require using such sophisticated test equipment as the Electronic Equipment Test Facility (EETF) and the Special Repair Activity (SRA). The EETF is a critical part of high-technology support, testing on one piece of equipment 78 different components. The importance of maintaining EETF availability begins to match that of the weapon systems it supports, with consequences for adequate sparing of repair parts, ensuring necessary manning and availability, and risk from enemy attack. And although the SRA, which substitutes a relatively small number of highly skilled repair personnel for the EETF's automated test equipment, is not as complex as the EETF, it is constrained by the expense and difficulty of getting those personnel with the necessary repair skills.

Beyond the cost and maintenance problems, there are also concerns about the increasing difficulty of estimating demand to support weapon systems like the Apache in wartime. For high-technology LRUs in the Apache MEP, the variance-to-mean ratio (VTMR)—a standard measurement tool that expresses the uncertainty of demand rate and is used in provisioning models when safety stock must be bought to account for temporal swings in demand rate—is typically much larger than the VTMRs assumed in inventory models and used in provisioning. Such unexpectedly high variability could exact painful costs in wartime.

But the problem is actually worse than simply expensive requirements for safety stock. As a large VTMR suggests, removal rates themselves are not stable; they change over time, thereby making reliable estimates of what to buy—at whatever cost—almost impossible.

In addition, fault isolation for particular Apache LRUs is often difficult, increasing the number of false removals, or no evidence of failures (NEOFs). The overall NEOF rate for the Apache mission equipment package is approximately 25 to 30 percent. This difficulty of fault isolation leads to the violation of another standard assumption of component failures—that they are independent events and, thus, that their arrival at a repair facility is uncorrelated with other arrivals. In fact, the more "related" one LRU is to another in the

weapon system, the more likely their removal rates are correlated positively.

The potentially extreme VTMRs produced by this correlation problem in turn pose dilemmas for predicting workload on intermediate-level test equipment, on the demand for transportation resources, and on the need for depot facilities.

The preceding paragraphs refer only to the uncertainties we "know." The greatest fluctuations in demand and workload will be a product not of variability in the inherent demand rate but of uncertainties associated with combat. To reduce the uncertainties of wartime support and to achieve payoffs from the Army investment, the logistics community must devise support solutions that work for high-technology weaponry like the Apache in wartime.

EVALUATING SUPPORT ALTERNATIVES

In the analysis, we examined five alternative support structures. The first two involved traditional solutions to weapon systems support, both of which relied on conventional continental U.S. (CONUS) depot support of forward intermediate repair. The "base case" structure featured slow transit time through the depot and required large stock investments, whereas the "improved EETF" structure was based on an excursion that assumed expenditures to improve EETF performance but that made no changes in the management of depot-level repair. The other three structures focused on responsive support, which means emphasizing fungible sources of support—repair, transportation, information, and management. These responsive support structures feature assured transportation for fast movement of critical components; expedited repair that minimizes turnaround time in the repair shop of these crucial items; and management systems with asset visibility geared at effective prioritization of repair and distribution.

Three responsive support alternatives were considered: an "enhanced depot," in which CONUS depot resources were made more responsive to wartime support needs by providing ensured transportation both in and between theaters; a "TADS/PNVS SRA," which involved evaluating the SRA; and an "extended SRA," which examined the benefits of extending SRA support to other critical Apache components beyond TADS/PNVS.

These five alternatives were evaluated in terms of comparative cost-effectiveness (for a given set of conditions, the preferred alternative needs to turn in more effective performance at equal or lower cost) and in terms of robustness (the preferred alternative needs to handle the uncertainties of war with minimal performance degradation).

The study focused on the high-technology components of the Apache, specifically its electronics, infrared imaging devices, laser components, and, in general, those parts of the Apache that are built on integrated electronic systems, and thus depend on equally sophisticated and complex computer-based fault diagnosis test sets.

Inputs for the study included a scenario involving two corps of Apaches using current tables of equipment (TOEs) applied to the Concept Analysis Agency's (CAA's) P90E Central European scenario. In addition, the Army's Unscheduled Maintenance Sample Data Collection (UMSDC) for the Apache was used to develop data for component reliability, which were used for the rate of failure, removal rate for LRUs, and variance in removal rate. We used the Dyna-METRIC model to calculate stock requirements for this scenario. EETF performance characteristics were generated from the RAM/LOG data collection effort, and for depot-level repair of TADS/PNVS LRUs, data from the Martin Marietta-operated SRA were used to determine test time, not reparable this station (NRTS) rates, and manpower demands. Transportation data were obtained from the logistics intelligence file (LIF).

We adapted the Dyna-METRIC model (developed within RAND's Project AIR FORCE) to make it applicable to the Army. The model allows us to represent removal rates, test equipment availability and capacity constraints, controlled substitution, repair part indenture, and repair overflows to higher echelons.

RESULTS

Cost-Effectiveness

In terms of cost-effectiveness, the two traditional alternatives—base case and improved EETF—have a costly support structure because they rely heavily on stocking expensive LRUs to cover surges in demand. In each case, cost was measured against constant effectiveness: the total amount of resources needed to sustain an availability goal (here set at a constant rate of 85 percent of mission equipment

package availability) over the scenario. The total cost of the base case for supporting two corps of Apaches in this intense scenario was $345 million. Improving performance of current theater-based test equipment yielded substantial savings of over $90 million. The most cost-effective alternatives, however, were the responsive support structures, with support costs for the three ranging from $187 to $205 million.

Robustness

We used three different tests for robustness in the evaluation: (1) assuming a 50 percent increase in demand rates over what was planned for and bought to support; (2) assuming greater enemy ability to damage repair facilities than expected; and (3) assuming the war continues longer than expected or longer than one expects to be able to afford.

In test 1, the standard structures both performed quite badly; the responsive support structures each maintained a level of performance well above that of the standard structure, with the extended SRA alternative clearly performing better than the other two. In test 2, the improved EETF alternative fared the worst—enhancing one element of the support structure apparently leaves the performance of the entire structure highly sensitive to change—while the base case and the three responsive support structures all performed about the same. In test 3, there is no real difference in total cost among the alternatives to support the longer war; however, in terms of risk reduction, the standard structures once again are most sensitive to the initial assumptions, showing no robustness to handle these unanticipated demands. As for the responsive support alternatives, they perform much better against the unexpected demands, with the exception of the narrowly constructed SRA structure, which performs poorly because it is understocked in those critical and high-demand items it does not repair.

CONCLUSIONS AND DIRECTIONS FOR THE FUTURE

The study found the standard support structures wanting and the responsive support alternatives superior. In terms of cost and robustness, the responsive support alternatives—especially the extended SRA and the enhanced depot structures—offer a means for providing cost-effective support of the Apache in a variety of conditions. The re-

search here substantiates the conclusion from a previous RAND effort on supporting the M-1 tank that the Army must increase the responsiveness in its logistics structures or face a loss in combat capability.

Adding high-technology subsystems to Army weaponry brings undeniable benefits in combat lethality and survivability, but it also brings serious problems for sustainability. Without substantial changes in philosophy and doctrine, the Army may find itself in a combat situation with weapon systems that do not work effectively, despite their vaunted capabilities.

Building a more responsive support system is certain to be a complicated and fairly extended task—one that involves dealing with the following major issues:

- Supporting currently fielded high-technology subsystems;
- Incorporating emerging Army support systems;
- Developing the necessary management tools to make responsive support work;
- Building proper, cost-effective support for the non-high-technology parts of Army systems; and
- Modifying support systems to handle the different needs of future weapon systems like the Light Helicopter.

ACKNOWLEDGMENTS

This study was originally proposed by then Commander of the U.S. Army Logistics Center LTG William Tuttle. We were further challenged in our approach to developing new responsive support structures by GEN Maxwell Thurman, then Commander of TRADOC. We are grateful to both of these senior generals for helping give our work intellectual focus.

This project could not have succeeded without the aid of COL David Sullivan, then Program Manager for TADS/PNVS. His openness in revealing the operation of the Special Repair Activity (SRA) was critical to our work; even more important were his ideas and pointed advice. COL Sullivan was an early proponent of responsive support and a key mover of creating "facts on the ground."

We are indebted to many people in the Army logistics community, both soldier and civilian, for aiding us in this project. Among them we would like especially to thank LTC Larry Dandridge, Earl West, Larry Nolde, MAJ William Hatch, and Charles Hanna at the U.S. Army Aviation Center, Fort Rucker, Alabama; Ray Henson of PMO TADS/PNVS; and Dale Cox, Charles Jones, and Phillip Drake of Martin Marietta Aerospace Corporation.

Individuals at RAND also were instrumental in the analysis and completion of this report. We would like to cite with gratitude Richard Bender, Richard Holland, Paul Steinberg, and Michael DiMaggio.

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TABLES

ABBREVIATIONS

ADS	Air Data System
AMC	Army Materiel Command
AMSAA	Army Materiel Systems Analysis Activity
ASL	Authorized Stockage List
AVIM	Aviation Intermediate Maintenance
AVUM	Aviation Unit Maintenance
BITE	Built-In Test Equipment
CAA	Concepts Analysis Agency
CAB	Combat Aviation Brigade
CONUS	Continental United States
CRAF	Civilian Reserve Air Fleet
CSA	Corps Storage Area
DASE	Digital Automatic Stabilization Equipment
DESCOM	Depot Support Command
DRIVE	Distribution and Repair in Variable Environments
EAC	Echelons Above Corps
EETF	Electronic Equipment Test Facility
EMC	Electronics Maintenance Company
FARP	Forward Arming and Refueling Point
FCC	Fire Control Computer
FLIR	Forward Looking Infrared
GPS	Gunner's Primary Sight
HARS	Heading and Attitude Reference System

UMMIPS	Uniform Materiel Movement and Issue Priority System
UMSDC	Unscheduled Maintenance Sample Data Collection
VISION	Visibility of Support Options
VTMR	Variance to Mean Ratio
WRM	War Reserve Materiel

1. INTRODUCTION

THE CHALLENGE OF HIGH TECHNOLOGY[1] FOR LOGISTICS STRUCTURES

The U.S. Army's combat logistics structure has evolved over many years. Why, then, is there a need to evaluate alternatives? What has changed, and what will change in the future? The answers to these questions are threefold.

First, the Army has begun to use, and will continue to use, increasing numbers of technologically sophisticated subsystems with components that are extremely expensive and hard to maintain and that have wartime demand rates that are difficult to forecast. The Army's current combat logistics structure evolved to cope with the very different types of problems posed by earlier generations of simpler weapon systems. These weapon systems primarily contained mechanical, hydraulic, and electrical subsystems (e.g., trucks, personnel carriers, and pre-M6OA3 tanks); for these systems, problems were easier to diagnose, test equipment was simple, and repair parts were relatively cheap.

Second, technicians alone cannot diagnose or repair complex subsystem faults. These technicians require sophisticated test and diagnostic equipment, which, in turn, complicates the logistics process and increases the associated capital expenditures. Compared to repair of simpler, more mechanical systems, repairing complex subsystems has decreased maintenance flexibility (i.e., there are no alternative tools, test equipment, or parts) and has increased the potential for misdiagnosed faults. Testing is particularly difficult on major weapon systems like the M-1 Abrams tank, the M-2/3 Bradley, and the AH-64 Apache helicopter, because these systems have multiple electronic

[1]"High technology" here refers to the complex, integrated, primarily electronic systems used for such functions as target acquisition and fire control in modern weapon systems. With the revolution in the small size, capability, and reliability of electronic microcircuits, the number of components in a box has grown exponentially, allowing complex signal processing and startling capability. This complexity may involve using information from many different pieces of equipment simultaneously. As a result, even slight internal anomalies can generate innumerable possible interactions. In these cases, troubleshooting is complicated, because the symptoms of a malfunction and the cause (or interacting causes) may be widely separated in the hardware (or software) and may occur only under particular operational conditions.

components and sophisticated optical sensors. It is unclear whether current Army logistics structures can fully accommodate these technologically sophisticated weapon systems. Indeed, the Army's large investments in these weapon systems may be undermined if logistics structures cannot ensure their battlefield availability.

Third, the high cost of individual components in sophisticated weapon systems further complicates the potential inadequacies in the repair process. For example, if broken components—line replaceable units (LRUs)—and their subcomponents—printed circuit boards (PCBs) or shop replaceable units (SRUs)—were relatively inexpensive (as are components for more traditional tracked vehicles and helicopters), then the Army could buy enough spare components and subcomponents to overcome temporary shortfalls in repair capability. However, sophisticated components are usually more expensive, often by orders of magnitude.

The high costs of these components make "buying one's way" out of the problem difficult—even more difficult given the already high investment costs of the test measurement and diagnostic equipment (TMDE) required at all echelons and of the highly skilled personnel required to repair LRUs and PCBs. Thus, in terms of total costs, buying repair components to support the current logistics structures is many times more expensive than it would be for more traditional and less technologically sophisticated components.

Still, one might be tempted to pay these costs if doing so could guarantee the combat availability of the weapon systems and if no other logistics structure was more cost effective. Unfortunately, we cannot forecast resource needs with sufficient accuracy to ensure that larger inventories would cover wartime demands.

In part, the inability to forecast resource needs results from the resource diversity of the logistics structures, with inventory and repair at echelons ranging from the battalion to the U.S. depot system. Movement of serviceable and reparable components among these echelons requires a transportation and distribution system. To maintain weapon systems availability, each function and echelon needs to have the proper resources in terms of LRUs, PCBs, TMDE, management, and transportation to ensure the availability of serviceable components each time a removal occurs.

The Army currently attempts to place sufficient wartime resources in each function at all echelons, which implies the ability to forecast

wartime demand rates. Unfortunately, accurate forecasts are impossible for three major reasons:

- Resource demands fluctuate erratically, thwarting forecasting even in peacetime.
- Wartime demand levels depend on wartime activity levels (or tempos), which can be forecast only by employing planning contingency scenarios. However, a real contingency is unlikely to ever match a planned scenario, especially in the unpredictable battlefield environment created by today's mobile forces.[2]
- Growing enemy capabilities create greater and increasingly unpredictable threats to repair, supply, and transportation resources.

Thus, Army provisioners find it frustrating when they attempt to forecast the wartime LRU demands for technologically sophisticated weapon systems like the AH-64 helicopter and the M-1 tank. Since they cannot accurately forecast the repair parts they will need, they cannot ensure combat vehicle availability merely by purchasing an apparently adequate number of spare LRUs.

Although forecasting problems undoubtedly existed with the older and less technologically sophisticated subsystems, it was simpler to diagnose those subsystems, their repair systems were naturally more flexible, and their spare parts were cheaper. These subsystems typically depended on people for repair—not on expensive TMDE—and repair parts could often be fabricated in the field.

Technologically sophisticated subsystems, on the other hand, depend more critically on complex logistics structures, on highly trained personnel, and on good fault-diagnosis equipment—and providing all these becomes increasingly difficult to ensure during wartime conditions. Thus, if a tank crew has a problem with its laser rangefinder, it must depend only on the maintenance and supply system, with its specially trained personnel, to return the weapon to action. And if the crew must resort to using the manual tank's systems, the increased firepower—paid for with scarce DoD dollars—is compromised.

[2]The priorities and tasking of units are unpredictable in a battlefield environment where the Army forces must wage campaigns of considerable movement to reduce vulnerability and to obtain positional advantage over a similarly endowed enemy. To succeed, Army forces will have to move rapidly to isolate enemy forces, thus creating unpredictable operations through a theater of operations. See U.S. Army, Field Manual FM 100-5, *Combat Operations*, May 1986.

MEETING THE CHALLENGE—DEVELOPING ALTERNATIVE LOGISTICS STRUCTURES

How can the Army meet the challenge of dealing with this environment? We hypothesize that a realistic solution involves developing and evaluating alternative logistics structures whose more fungible resources—like transportation and repair—are made *responsive* to changing wartime demands.

Using data on the high-technology subsystems of the AH-64 Apache attack helicopter,[3] our research hypothesizes alternative logistics structures and assesses their responsiveness—in terms of improvements to weapon system availability—under contingency scenarios. While this research closely parallels our earlier M-1 investigation, there are some major additions. For example, we demonstrate the impact of providing constrained theater depot-level repair for critical LRUs, and we examine trade-offs of automated TMDE against specialized test equipment of Special Repair Activities (SRAs) and improved distribution and depot management for CONUS depots. This study also more carefully examines the wartime robustness of each alternative logistics structure.

ORGANIZATION OF THIS REPORT

Section 2 delves more deeply into the problems of sustaining high-technology subsystems, and Sec. 3 describes the approaches used to evaluate alternative logistics structures. Section 4 provides the evaluation results, and Sec. 5 presents the conclusions and describes the next steps in our research.

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[3]When we discuss high-technology subsystems, we are referring principally to the problems the new high-technology electronics create for logistics support. For example, the T700 turbine engine that powers the Apache is highly advanced, but in support terms, it presents few if any of the difficulties usually seen in modern electronic subsystems.

2. SUPPORT PROBLEMS FOR HIGH-TECHNOLOGY SUBSYSTEMS

This section describes the problems of maintaining high-technology weapon subsystems (specifically high-tech Apache subsystems)—a concern that will increase as high technology plays an increasingly significant role in future weapon systems. Following a discussion of high technology in the Apache, we examine some of the support problems associated with it, including high cost, difficulty of repair, variability in the inherent demand rate, and the uncertainties of wartime.

HIGH TECHNOLOGY IN THE AH-64 APACHE

The Apache's mission equipment package (MEP) adds significantly to the helicopter's capabilities, making it the most advanced and most lethal attack helicopter in the world. The major subsystems of the Apache's MEP include:

- Target Acquisition Designation Sight/Pilot Night Vision Sensor (TADS/PNVS);
- Fire Control Computer (FCC);
- Multiplex Data Bus Assembly (MUX);
- Symbol Generator;
- Integrated Helmet and Display Sight System (IHADSS);
- Heading and Attitude Reference System (HARS);
- Doppler Inertial Navigation Unit;
- Air Data System (ADS).

The TADS sensor system allows the Apache to acquire, designate, and track targets during inclement weather, restricted visibility, or at night. The PNVS forward looking infrared (FLIR) system permits all-weather, day/night navigation, even in nap-of-the-earth flying. The main Apache armament is the HELLFIRE antiarmor missile. A semi-autonomous weapon system, it homes in on laser designators, which can be transmitted from the firing Apache, from another Apache, a scout helicopter, or from a ground-based laser source. The TADS—operating in concert with the FCC, the IHADSS, and the Symbol Generator—provide target acquisition designation and

weapons guidance. On-board sensors include TV, FLIR, direct-view optics, and a laser tracker. The TV system operates in the near-infrared region in both wide and narrow field of view, and the FLIR is capable of both day and night target acquisition in three field of views.

Both TADS and PNVS-acquired imagery can be routed through the IHADSS—a helmet-mounted display that provides a two-dimensional TV-type image on a one-square-inch monocle for both the pilot's and copilot/gunner's helmets. The Symbol Generator provides flight director symbology that is superimposed on the FLIR picture to afford a "heads-up" flying condition. Both the PNVS and TADS—as well as the 30-mm chain gun—can be slaved to the pilot's or copilot's line of sight through the IHADSS's electro-optical head tracking system.

To ensure on-time and accurate arrival of the Apache on station, the MEP includes a Heading Attitude Reference System and a Doppler Navigation Unit, which provide precision navigation. The TADS and helmet-mounted displays continuously provide the crew with this and other information.

The MEP architecture is based on a dual MIL-STD-1553A multiplex data bus and an integrated cockpit control/display configuration. This architecture incorporates multiple system processors for such functions as navigation, fire control, and command and control.

HIGH COSTS OF HIGH-TECHNOLOGY COMPONENTS

The Apache's advanced capability does not come cheaply. Table 1 shows how some of its LRU unit costs compare with those for the M-1, revealing that Apache LRUs are many times more expensive. Compared with non-electronics, these components are substantially more expensive (with some exceptions, such as the engine and rotor blades). Overall, the high-technology slice of the Apache costs proportionately far more than it does in other major Army weapon systems. These high-technology components are also relatively more troublesome than the low-technology LRUs, comprising a disproportionate share of the repair workload. Although the high-tech components represent only 25 percent of the LRUs, they account for almost 50 percent of all removals, and 75 percent of removals weighted by dollar value (see Fig. 1). High removal rates and high unit costs combine to make efficient and rapid repair and return to service of great mission importance.

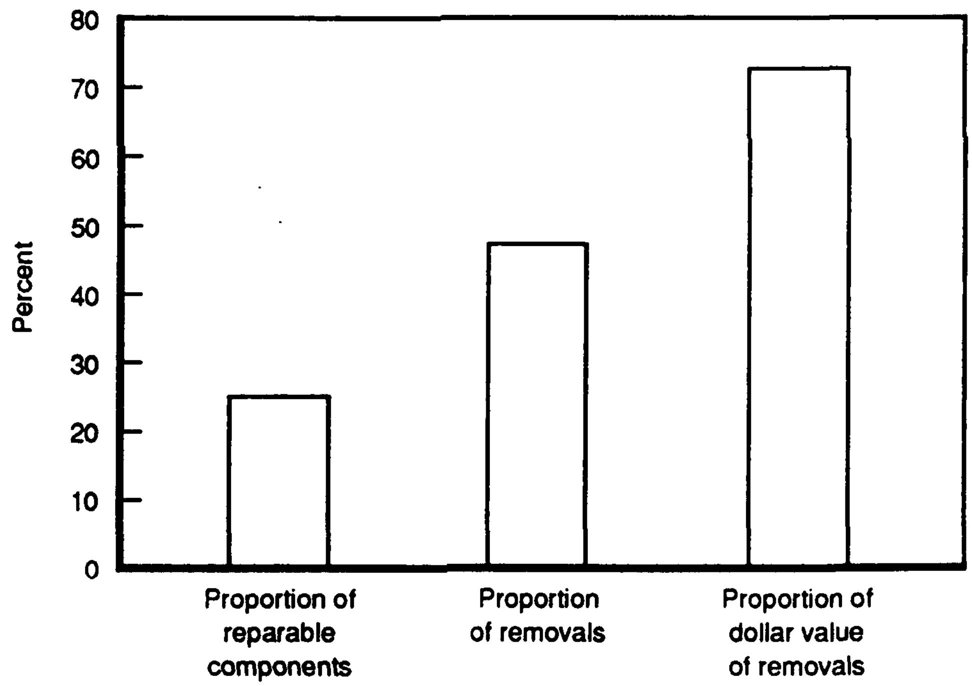
Table 1

Top Ten Electronics LRUs by Unit Cost in Apache and M-1

Apache	Unit Cost	M-1	Unit Cost
Night sensor assembly	$164,767	Thermal receiver unit	$76,019
PNVS turret assembly	161,480	Power control unit	56,359
TADS turret assembly	150,082	GPS body assembly	51,067
Day sensor assembly	150,082	Computer	10,337
TADS electronic unit	89,069	TIS electronic unit	13,015
Optical relay column	87,141	Laser rangefinder	22,270
Laser transceiver unit	63,134	Turret networks box	17,209
HARS	62,400	TIS image control unit	11,123
MRTU Type III	42,446	Gun turret drive electronics	6,974
Television sensor assembly	39,018	Servomech traverse	5,729

SOURCE: Army Master Data File, 1988.

NOTE: Abbreviations are defined on p. xix.



Source: Unscheduled Maintenance Sample Data Collection, 1987–1988.

Fig. 1—High-Technology Proportion of Apache Workload

DIFFICULTY OF REPAIR FOR HIGH-TECHNOLOGY EQUIPMENT

Not only are the high-technology portions of the Apache a relatively large part of the workload, they also present serious problems about how to maintain them at all. Low-technology/mechanical systems have traditionally benefited from their low cost and their inherent flexibility. With relative ease of diagnosis and repair, much of the maintenance on previous generations of weapons could be performed by the crew itself. The repair tools needed—wrenches, simple volt-amp-ohm meters, and the like—were cheap and could be made plentiful; the parts needed to make fixes were similarly inexpensive and rugged. In fact, quite often in such systems, a broken part could be overcome with field fabrications or innovative adaptations (e.g., "short tracking" to temporarily repair a broken track).

However, reliance on high technology eliminates these previous sources of flexibility in the support structure, sources that allowed an operating unit to be relatively free of shortcomings in the rest of the logistics system. Spare high-tech LRUs and the repair parts to fix them have become expensive and scarce commodities; in addition, the repair tools needed to fix broken LRUs have become complex and extremely expensive—as have the skills needed to make repairs, which are now far beyond the capabilities of any operator crew. Instead, fault isolation of failed (or apparently failed) components depends on built-in test equipment (BITE)—the fault detection/location system (FD/LS)—on the aircraft itself. Repair of the removed failed component cannot be accomplished forward; rather, LRUs must be evacuated to a secure location in the rear where complex, bulky, and expensive test equipment can be safely located. Thus, high-tech systems depend much more on a responsive logistics structure for adequate operation.

Maintenance Facilities

For the Apache, repair of LRUs in theater can be (and is being) accomplished at either an Electronic Equipment Test Facility (EETF) or at a Special Repair Activity. The EETF is an automated test facility located in the corps support area in wartime; thus, no intermediate repair would be executed forward of the corps rear area. The EETF is an expensive piece of test equipment—at $10 million each, it begins to approach the cost of the Air Force's avionics intermediate shop. It is also complex, consisting of an AN/USM-410 EQUATE core computer,

AH-64 peculiar subsystem, electro-optical bench for repairing certain TADS/PNVS LRUs, and software packages (test program sets of TPSs) for each LRU it tests. The EETF represents a new concept in Army support philosophy: a single piece of highly advanced equipment that can test and fault-isolate 78 different types of LRUs. The criticality of a system like the EETF to maintaining the Apache makes its availability comparable to that of the weapon system itself. The ability of the EETF to execute its wartime mission might be adversely affected by, among other things, lack of adequate sparing (in ASLs or war reserve), inadequate manning to maintain the needed shifts, frequent movement, or destruction by nearby enemy forces.

SRA is an Army term for contractor-maintained[1] repair facilities, usually located near operating bases that can offer mixes of both intermediate- and depot-level repair. Currently, Martin Marietta operates four SRAs to support fielded Apaches. SRAs substitute a relatively small number of highly skilled repair personnel for the automated test equipment of the EETF for some critical LRUs and SRUs; its repair equipment tends to consist of breadboarded test stands and hot mock-ups. On the other hand, the necessary repair skills at the SRA are rather expensive, with a fully burdened yearly cost of $180,000 per technician.[2]

Need for Accurate Estimates of Combat Support Needs

With all parts of the repair structure now much more expensive, the ability to support the new high-technology weapon systems depends more than ever on being able to accurately estimate spares demands, workloads on test equipment, and the need for repair parts and repair personnel. To buy spare parts to fill repair pipelines requires fairly precise estimates of what the need for spare parts will be; however, given the high unit costs of LRUs, almost any level of "safety stock" above what is needed may prove to be too expensive. The same is true for expensive test equipment. Given its cost, the Army has problems in trying to buy enough to ensure spare capacity; thus, any "surprises" in the level of workloads these test sets must handle will result in queues, backlogs, and broken LRUs flooding the pipelines. Thus, the cost of spares and repair, as well as the greater reliance

[1]They also could be manned by DoD personnel typically found in similar Army Materiel Command (AMC) depot facilities.

[2]Program Manager's Office, TADS/PNVS.

that high technology places on all parts of the logistics structure, would seem to demand that the Army be able to predict just what level of resources it will need to support weapon systems like the Apache in wartime. Unfortunately, the nature of high-technology systems makes these estimations *more uncertain* than before.

SOURCES OF DEMAND UNCERTAINTY

Uncertainty in High-Technology Equipment

High technology has introduced types of uncertainties that make it much more difficult to reliably estimate combat support needs. Specifically, the inadequacy of BITE makes fault isolation inefficient, thus leading to large numbers of no evidence of failures (NEOFs—boxes removed that turn out not to be faulty). In addition, fault isolation to the SRU level is problematic, thus leading to inefficiency in repair and high levels of items that are not reparable this station (NRTS)and must be sent to a higher echelon. These and other factors lead to large levels of variability—and hence unpredictability—in the inherent removal rates and pipelines for LRUs.

Uncertainty in the Wartime Environment

Unpredictability in the inherent demand rate is just one source of uncertainty, and it is conceivably the least important one. The unpredictability of wartime itself complicates any attempt to estimate combat support needs. Since logistics demands are related to wartime tempos, the pace of the war will determine the level of logistic support needed. (Logistics resources are in part budgeted on the basis of computer-modeled scenarios.) However, any real war will differ from what is anticipated in peacetime. For example, the pace of operations may be far greater than expected, or different units may be called on to fight more or less intensely than had been anticipated. In addition, the disparity in demands among units may grow as maneuver units gain greater mobility and firepower. Thus, the overall level of resources needed, as well as their distribution among units in the theater, may be wildly misguessed in peacetime.[3]

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[3]For a description of the wartime environment that leads to this difficulty of prediction, see U.S. Army, Field Manual FM 100-5, *Combat Operations*.

The enemy's ability to threaten logistics targets even fairly far in the rear adds another crucial element of unpredictability to wartime logistics needs. For example, damage to a piece of test equipment functions almost exactly like fluctuations in the demand rate: reducing the availability of test equipment time (by blowing up a test stand) is equivalent to seeing an unexpected rise in the demand rate for the LRUs that cross that test stand. Yet here too it is virtually impossible to predict in peacetime what the ability of the enemy will be to interrupt the support structure.

The revolutionary changes shaking the world's geopolitical structure add what is probably the greatest uncertainty to any planning for logistics. The Army of the future will no doubt be smaller and, while high-intensity combat in Europe will remain a concern, the Army may find that the demands for versatility, deployability, and sustainability in any number of contingencies scattered around the globe may be of equal concern.[4]

Uncertainty Demonstrated by Peacetime Demand Rates

Of these sources of uncertainty, we know the most about demand rate variability. We illustrate it here not because it is the most important—in fact, it may be the least—but because it demonstrates the existence of uncertainty even in low-level peacetime operations.

VTMR as a Measure of Uncertainty. The variance-to-mean ratio (VTMR), which expresses the uncertainty of the estimated demand rate, is a standard measurement tool in provisioning models when safety stock must be bought to account for temporal swings in demand rate. The VTMR is a well-established concept in inventory theory and is used in many military supply models, such as the Army's SESAME model. In inventory theory, demands follow a Poisson arrival process, which has a VTMR of 1. The further the actual VTMR is from 1, the poorer the fit of the Poisson model.[5] In practical terms, if one bought spares assuming a VTMR of 1, unanticipated shortfalls

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[4]GEN Carl E. Vuono, "The Strategic Value of Conventional Forces," Tenth Annual Bernard Brodie Lecture on War and Politics, University of California, Los Angeles, June 1, 1990.

[5]Some logistics models, like SESAME in the Army and Dyna-METRIC (see Sec. 3), can deal with VTMRs greater than 1.

would occur in the highest demand periods, depending, of course, on the responsiveness of the repair system.[6]

Figure 2 shows the distribution of VTMRs for high-tech LRUs in the Apache MEP. These VTMRs are typically larger than those assumed in inventory models and used in provisioning, and such unexpectedly high variability could exact painful costs in wartime. For example, if the Apache force were provisioned with spares for wartime according to standard assumptions (i.e., VTMR = 1) but wartime demand rates instead exhibited the VTMRs seen in Fig. 2, a falloff in aircraft availability might occur (as seen in Fig. 3). In this example,[7] pipelines for a standard support structure are bought out with the standard assumption of demand rate variance to achieve a goal of minimum 85 percent availability. Instead, the higher VTMRs result

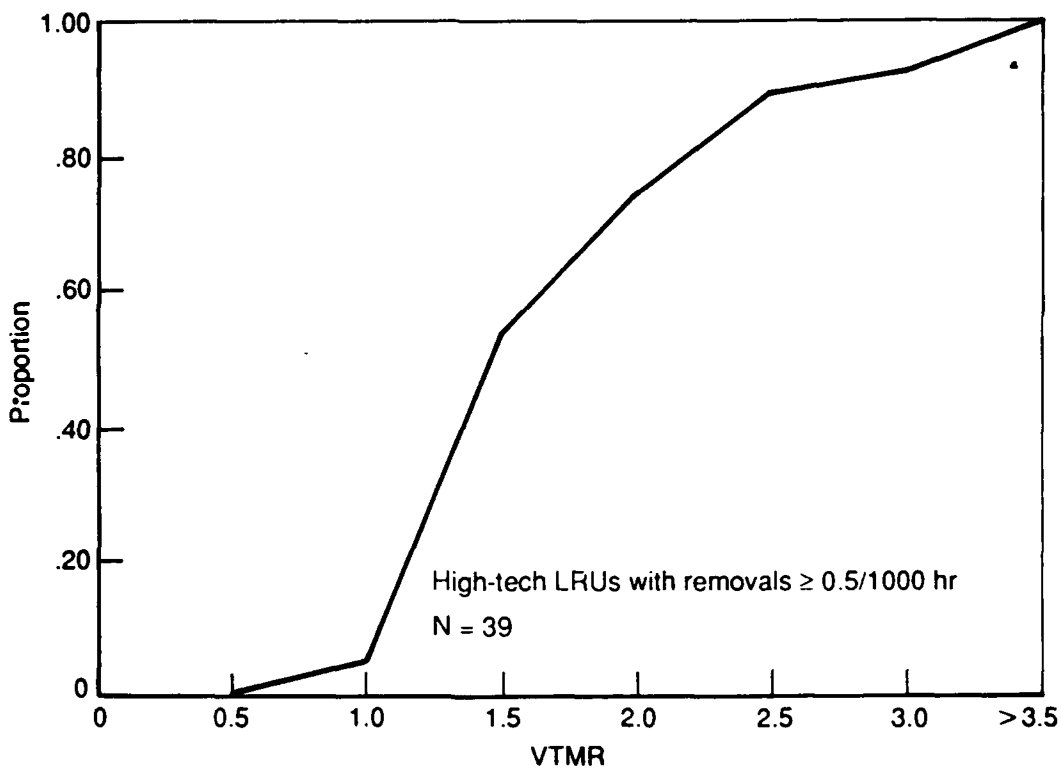

Fig. 2—Cumulative Distribution of VTMRs in Apache High-Tech LRUs

[6]See R-3673-A, p. 11.

[7]This example employs the Dyna-METRIC model and data sources as discussed in Sec. 3. It shows availability of Apaches in two corps (306 aircraft) across 120 days of the Concept Analysis Agency's P90E scenario.

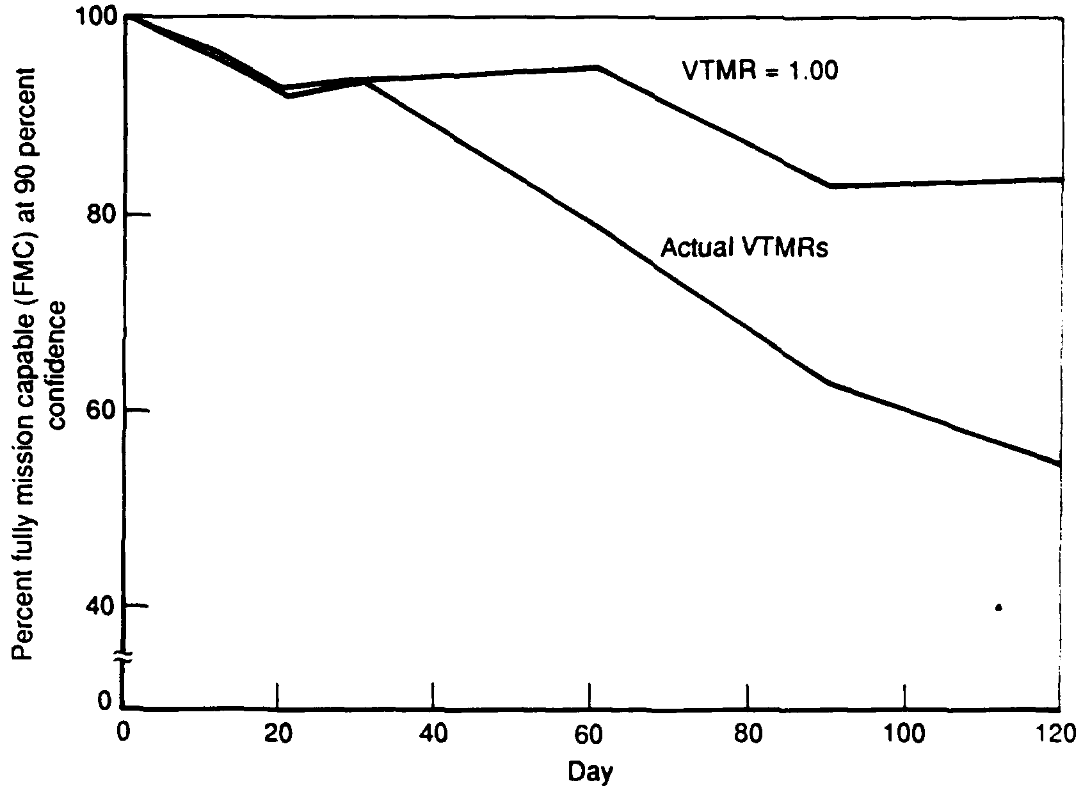

Fig. 3—Apache Availability with Stock Bought for VTMR = 1.00 and Actual VTMRs

in reduced performance, with aircraft availability dropping as low as 50 percent. To actually achieve the flying goal would require buying $80 million in additional stock over the $220 million calculated for standard VTMRs, or an increase of almost 40 percent.

High VTMRs are in themselves not a serious problem. Models can be reconfigured to handle VTMRs larger than 1, such as by using the negative binomial distribution in place of the Poisson. Nor are these high VTMRs necessarily an exclusive problem with high-tech components; the same type of high variability can plague less complex technology as well. The fundamental problem, as the last paragraph suggested, is the effect such high variability can have on affordability of stock requirements. This level of unpredictability, when combined with LRUs that can cost over $160,000 (and SRUs in TADS/PNVS that can cost over $40,000), means that buying out levels of uncertainty represented by these VTMRs may strain Army budgets to the utmost and do so at a time when money is in very short supply.

Instability in Demand Rates. But the problem is actually worse than simply expensive requirements for safety stock. As a large VTMR suggests, removal rates themselves are not stable; they change over time, thereby making reliable estimates of what to buy—at whatever cost—almost impossible. Provisioning is typically based on removal rates from a period of one year, or at most two, with no indication as to how reliable those rates may be. As Fig. 4 demonstrates, they are not likely to be reliable at all. Evidence from removal rates and VTMRs for M-1 Abrams tank LRUs over time show little stability, and no predictability of what removal rates (and their associated VTMRs) are likely to be in the future.[8] Even seemingly stable cases cannot be assumed to remain so predictable; as Fig. 5 shows, the M-1 turret networks box maintained a fairly stable removal rate for six years, only to suffer a substantial jump in the seventh.

As a result, buying based on some set of removal data will likely be wrong, perhaps wildly so. Previous RAND research on the M-1 compared removal rates in 1985 and 1986.[9] It found that if stock were bought using removal data from 1985 and the system fought in combat exhibiting removal behavior like that seen in 1986, some $411 million worth of stock meant to maintain 85 percent availability for a corps of tanks would yield only 25 percent availability; if the case were reversed (buy at 1986 rates, fight at 1985), $654 million meant to buy 85 percent availability would produce only 35 percent of the tanks able to fight.

The reasons for these fluctuations are not well understood. LRUs may get "well" as repair personnel learn to service them better. Other boxes may tend to get "sick" after block modifications are made, resulting in different performance characteristics. As the weapon system hardware or software are upgraded, with new capabilities added, fault isolation to a particular LRU may become more difficult, increasing the number of false removals or NEOFs. While explanations are frequently available after the fact for changes in removal rates, these changes cannot be predicted or anticipated.

[8]Demand rate variability over time can best be seen in a mature weapon system like the M-1. We expect that demand rates would be especially volatile in the early years of fielding of a new system like the Apache. Consequently, we use multiyear data from the M-1 Sample Data Collection effort to demonstrate unpredictability of demand rates. See also Gordon Crawford, *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, RAND, R-3318-AF, January 1988.

[9]R-3673-A, App. A.

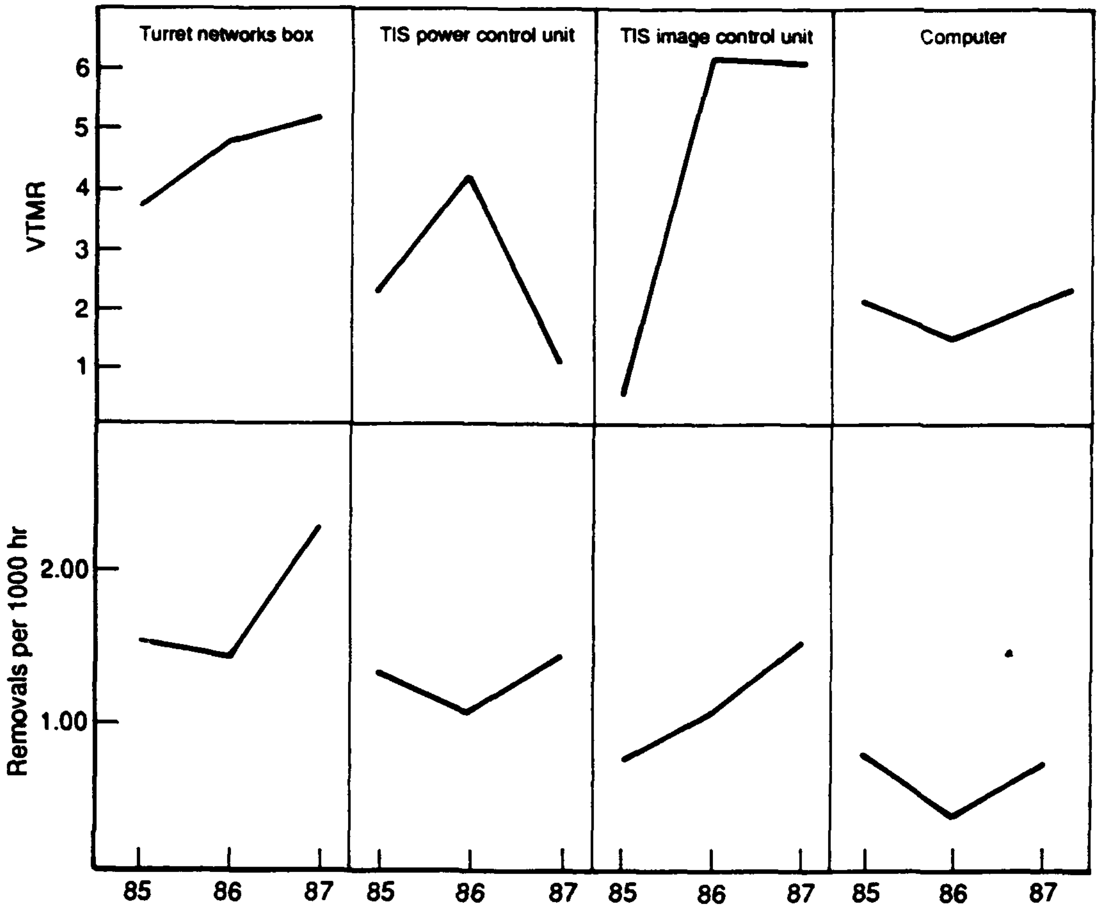

Fig. 4—Variability in Selected M-1 LRUs, 1985–1987

No Evidence of Failures. Like most high-technology weapon systems, the Apache suffers from high NEOF rates. The complexity of modern technology, the integration of electronic architectures through both hardware and software, and the mixture of electronic and analog components (as in electro-optical systems) make fault isolation exceedingly difficult. The overall NEOF rate for the Apache MEP is approximately 25-30 percent, comparable to that for the M-1 tank high-tech components. Twenty-nine percent of all TADS/PNVS removals sent back to the SRA were found to be without fault;[10] Fig. 6 shows that for some high-driver LRUs at Fort Rucker, the Army Aviation Center, NEOF rates may be as high as 50 percent.

[10]Derived from data obtained from Martin Marietta Aerospace Corporation Product Support Division.

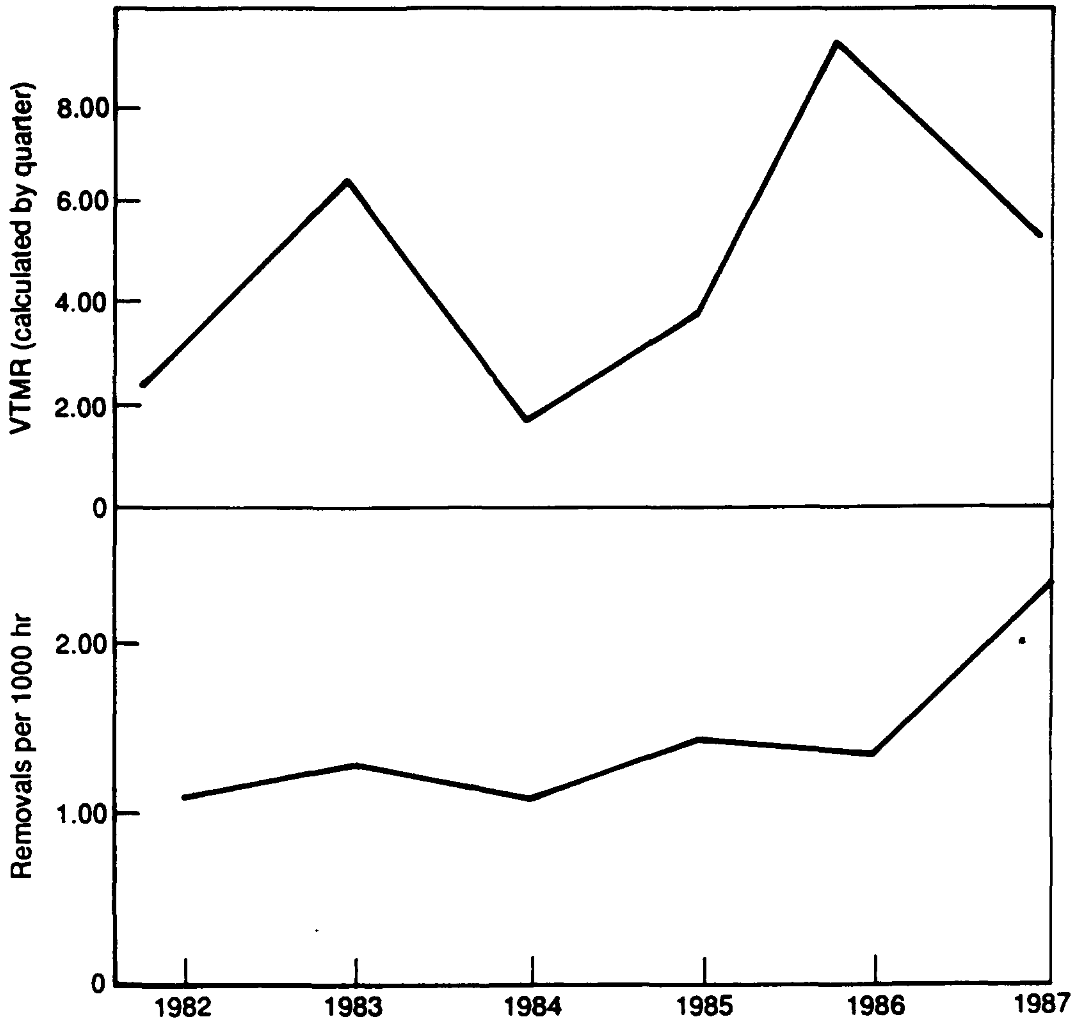

Fig. 5—Variability in Turret Networks Box Removal Rate, 1982–1987

NEOFs result from diagnostic problems at the flight line. An Army study found that approximately 40 percent of all FD/LS-reported faults were in error.[11] When maintainers cannot isolate a fault with the built-in test equipment, they often solve the problem by removing many boxes to fix one fault (we call these events "chains"). At Fort Rucker, chains occurred in over a quarter of all incidents in which a high-tech failure was reported; in those cases, it took more than three

[11]U.S. Army Aviation Development Test Activity, *Logistical Evaluation Test of the AH-64A Advanced Attack Helicopter Electronics Equipment Test Facility (EETF) and Fault Detection / Location System (FD / LS), Vol. II: Final Report,* September 1987.

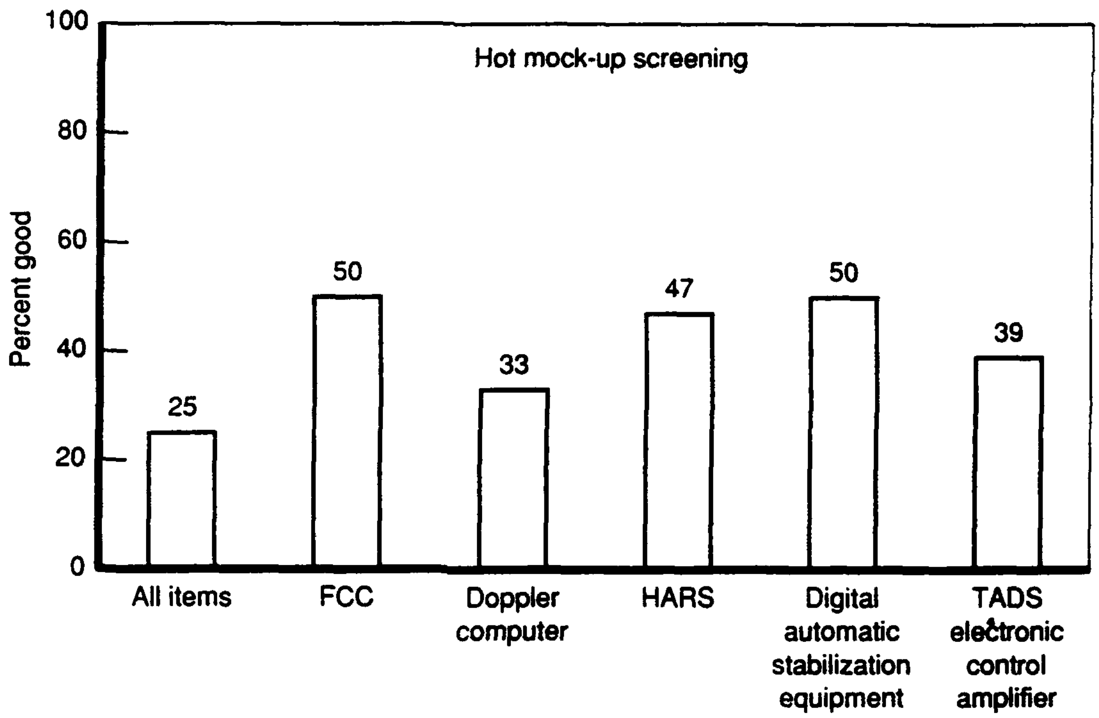

Fig. 6—No Evidence of Failure Rates for Selected High-Tech Apache LRUs

removals on average to make the fix.[12] The use of such a large number of spares to make a fix at the flight line puts additional stress on the need for spares and, consequently, on the support structure to repair and return boxes that come to them as rapidly as possible.

Non-Independence of Removals. The difficulty of fault isolation, which partly results from the integrated nature of modern electronic subsystems, leads to the violation of another standard assumption of component failures: that they are independent events and that their arrival at a repair facility is thus uncorrelated with other arrivals. In fact, the more "related" one LRU to another in a weapon system, the more likely their removal rates are to be correlated positively. Figure 7 provides evidence on this phenomenon, again from the M-1 experience. It shows removal rates by quarter over a one-year period for the

[12]Derived from the AH-64 RAM/LOG data collection effort.

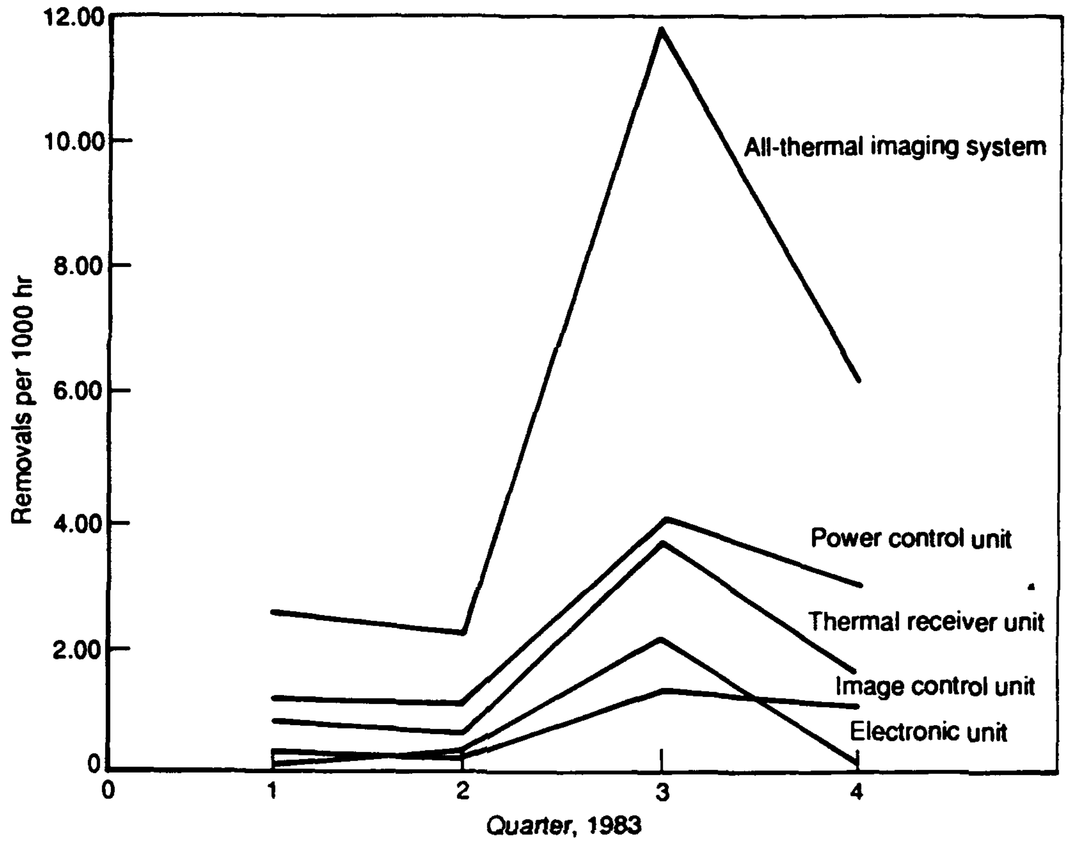

Fig. 7—Variability in Test Equipment Workload (M-1 Thermal Imaging System Test Set)

four LRUs that make up the thermal imaging system (TIS), both by individual LRU and for all four LRUs taken together. As can be seen, the removal rates of these components are in fact not independent: they rise and fall together in groups. This makes the variance in the removal rates for all four boxes taken together much larger than for any individual box.

Unpredictable Loads on Test Equipment. These potentially extreme VTMRs pose dilemmas for predicting workload on intermediate-level test equipment, on the demand for transportation resources, and on the need for depot facilities. For example, the four components of the M-1 TIS are all repaired on a single piece of dedicated test equipment, the thermal system test set (TSTS). Like stock, repair equipment may be provided based on anticipated loads and on

the variability of those loads. If a VTMR of 1 is anticipated, much larger variability will produce unexpected queues on test equipment, with resultant backlogs of work and non-mission-capable weapon systems. As Fig. 7 shows, the jump in removal rates for TIS components in the third quarter of FY83 may have resulted in much greater TSTS workloads than anticipated.

Figures 8 and 9 illustrate the problems involved in repairing Apache components. Figure 8 shows the removal rates by week for EETF-reparable components, with the horizontal line in the figure representing the two-standard-deviation limit, if the VTMR were 1: that is, under standard assumptions, the removal rate of these components should fall under this line more than 95 percent of the time. In fact, almost 20 percent of the time, the removal rate of EETF-reparable items is greater than that assumed in computations.

Figure 9 presents similar information about SRA workload based on inductions on a weekly basis for SRA-reparable items from the Fort Rucker and Fort Hood SRAs. The non-independence of TADS/ PNVS LRUs means that the variability in the workload will be greater than anticipated; in fact, almost 25 percent of the time, the weekly inductions lie above the two-standard deviation line. In other words,

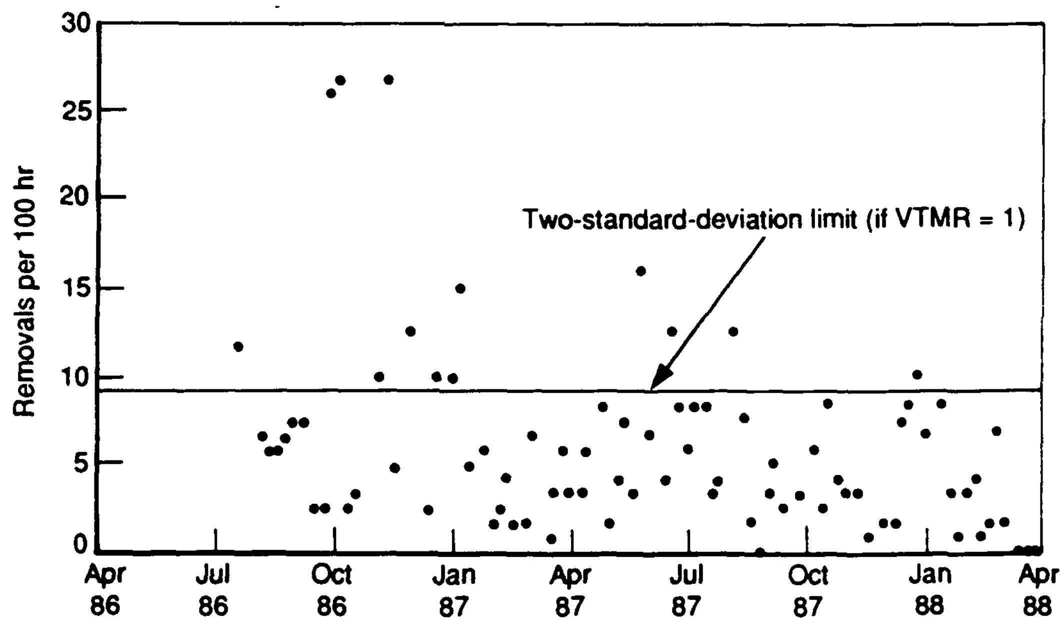

Fig. 8—Variability in EETF Workload

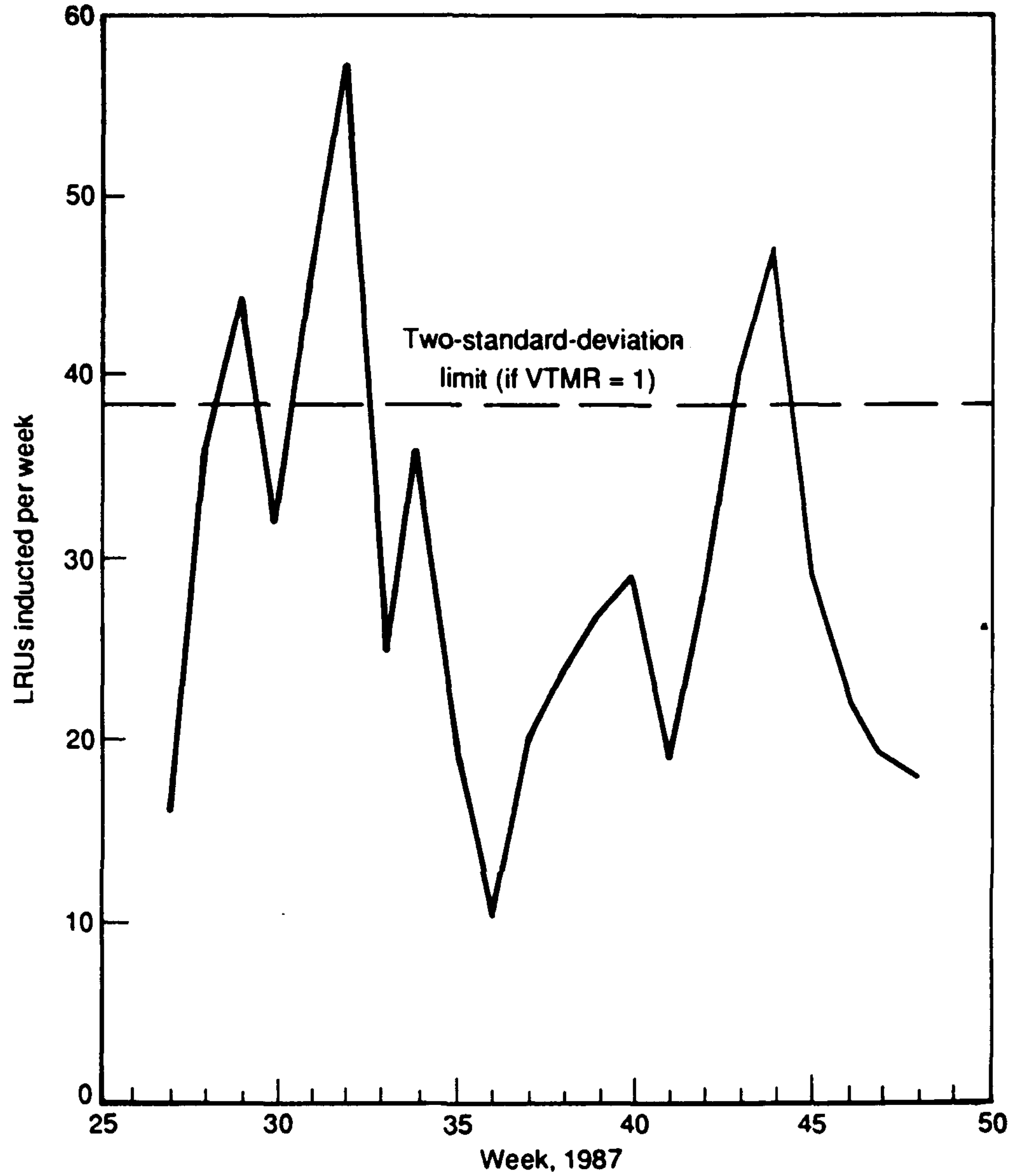

Fig. 9—Variability in AH-64 SRA Inductions (Fort Hood and Fort Rucker)

the workload at the SRA is greater than the "maximum" about 10 times more often than predicted.

Implications for Wartime. All the preceding data refer only to the uncertainties we "know." The greatest fluctuations in demands and workload will be a product not of variability in the inherent demand rate—they will result from the uncertainties associated with com-

bat.[13] Only in the most benign of combat environments will modern high-technology weapon systems not face the problem of insufficient spares and frequently overloaded test equipment. Thus, the effectiveness gained from the Army's heavy investment in extremely expensive weapon systems may be severely reduced by their unavailability when they are most desperately needed.

To reduce the uncertainties of wartime support and to achieve payoffs from the Army investment, the logistics community must devise support solutions that will work for high-technology weaponry in wartime. In a period of tight budgets, these solutions must be cost-effective; however, they must also be robust enough to overcome the unpredictability of wartime. The next section offers a methodology to examine such cost-effective and robust alternatives.

[13]In Operation Just Cause in December 1989, for example, Apaches experienced unanticipated maintenance problems when high-technology components failed, apparently from the effects of "jungle humidity." See *Aerospace Daily*, Supplement, January. 31, 1990, p. 77. On the other hand, the first Apaches rotated to the National Training Center at Fort Irwin, California, suffered unanticipated maintenance problems with these high-tech LRUs in the Mojave Desert when sand clogged air filters. "Apache Uprising: Tank-Killing Chopper Takes to the Warpath at National Training Center," *Army Times*, April 3, 1989.

3. EVALUATING SUPPORT ALTERNATIVES

High cost, difficulty of repair, variability in the inherent demand rate, and the uncertainties of wartime strongly suggest problems in supporting the Apache mission in combat and argue for investigating alternative solutions for providing that support.

METHODOLOGY

Two criteria are paramount in constructing a viable structure for supporting the Apache in wartime operations. The system must be *comparatively cost-effective*; that is, for a given set of conditions, the preferred alternative needs to turn in more effective performance at equal or lower cost. In addition to the cost criterion, the preferred system must demonstrate *robustness*; it must be able to handle the uncertainties of war with minimal degradation of performance better than alternatives. Neither criterion is exclusively important. For example, low cost is to be valued unless it cannot guarantee minimally effective performance given the uncertainties of war, and robustness is a necessity for combat support, unless the cost of achieving it requires forgoing equally valuable goals.

This study presents a methodology for evaluating support alternatives and attempts to measure the potential benefits of responsive support versus traditional support structures. It does not seek to determine requirements, whether in terms of stock, repair capacity, or transportation assets. Given the unpredictability of wartime demands, calculating requirements for modern warfare is a much more difficult task than in the past. RAND is currently pursuing work aimed at developing new methodologies for calculating wartime requirements, and we hope that work persuades others to reexamine requirements development.

If analysis cannot say how much support is needed, what can it do? Given the unpredictabilities of wartime, what answers can analysis provide? We believe we can determine the relative value, including cost-benefit, of different support alternatives, even without reliable estimates of wartime demands. It is presumed in this type of analysis that alternatives that perform better, or are more cost-effective, against some set of varying conditions—against "known" uncertain-

ties—will be more likely to outperform competing alternatives against the unknown conditions of wartime. This study seeks *relative* measures of benefit. In other words, although we cannot say for sure that one structure will deliver some set goal of aircraft availability for a certain cost or will save a set number of dollars versus another structure for all possible wartime environments, we can say that one structure will perform better than another structure, will tend to cost less, will deliver more combat punch, and will handle surprises better against a wide variety of contingences.

The following paragraphs lay out the focus of our study, the inputs it uses, the model it employs, and the alternative support structures it examines.

FOCUS

Our research focuses exclusively on the "high-technology" components of the AH-64 helicopter. This is not to deny that other parts of the helicopter—engine, rotor system, hydraulics, etc.—are important to the weapon's effectiveness. But we believe the evidence shows that high technology is a special problem deserving in-depth focus and that high technology presents the Army with problems it has heretofore rarely encountered and for which it has not developed effective strategies.

The "high-technology" components tend not only to be expensive but are hard to fault-isolate and repair; they also tend to have high removal (if not failure) rates. Given this, high-performance turbine engines (which are extremely reliable) and composite rotor blades (which are easy to troubleshoot) may be "high tech" compared to their predecessors, but they do not suffer from the types of problems of interest here. This study focuses on electronics, infrared imaging devices, laser components, and, in general, those parts of the Apache that are built on integrated electronic systems and, thus, depend on equally sophisticated and complex computer-based fault diagnosis test sets. In determining which components to include in the study, we used three criteria:

1. The component can be repaired on the Electronic Equipment Test Facility and has a test program set prepared for it;
2. If the component is not already reparable at the EETF, it is part of the TADS/PNVS;

3. If not EETF-reparable or part of TADS/PNVS, the components are composed of integrated electronics embedded in the electronic suite of the Apache MEP, and are costly.[1]

Appendix C lists all LRUs modeled in this study.

INPUTS

Scenario

We modeled two corps of AH-64s using current TOE applied to the Concept Analysis Agency's P90E Central European scenario. At the maximum, 306 aircraft are represented in the study, with several battalions deploying after Day 30 of the war. The two corps are made up of 11 combat aviation brigades (CABs) located at division and corps level. Although this scenario is for Central Europe, the variability in operating tempos it creates across the engaged units is reasonably reflective of what would face Army logisticians in other cases. Thus, this case serves as a reasonable proxy for the kind of nonlinear operating tempo expected in other contingency operations.

The scenario provides postures for each brigade for each day of a 120-day scenario. Flying rates are determined by the level of activity of the ground maneuver units in the division (or corps) that the CAB is attached to. The intensity of operations depends on the level of engagement of the division. When the division is disengaged, Apaches are expected to average roughly two flying hours a day in routine patrolling operations; with one ground maneuver brigade engaged, average aircraft sorties will total four hours a day; and with two of three brigades engaged, the Apaches will be expected to fly six hours a day. When more than two brigades are engaged, additional support will be supplied by Apaches in the corps CAB. Corps CAB operations are not independently modeled, and deep battle operations are not explicitly accounted for; instead, we assumed that the operational demands on the corps CAB will reflect the intensity of fighting among the corps' divisions.[2]

The logistics structure of the two corps is standard Army form (see Fig. 10). Helicopters operate out of forward arming and refueling

[1]This residual category includes parts of the IHADSS, the FCC, and the HARS.

[2]Apache operating tempos were generated from information supplied by the U.S. Army Aviation Center, Fort Rucker, Alabama.

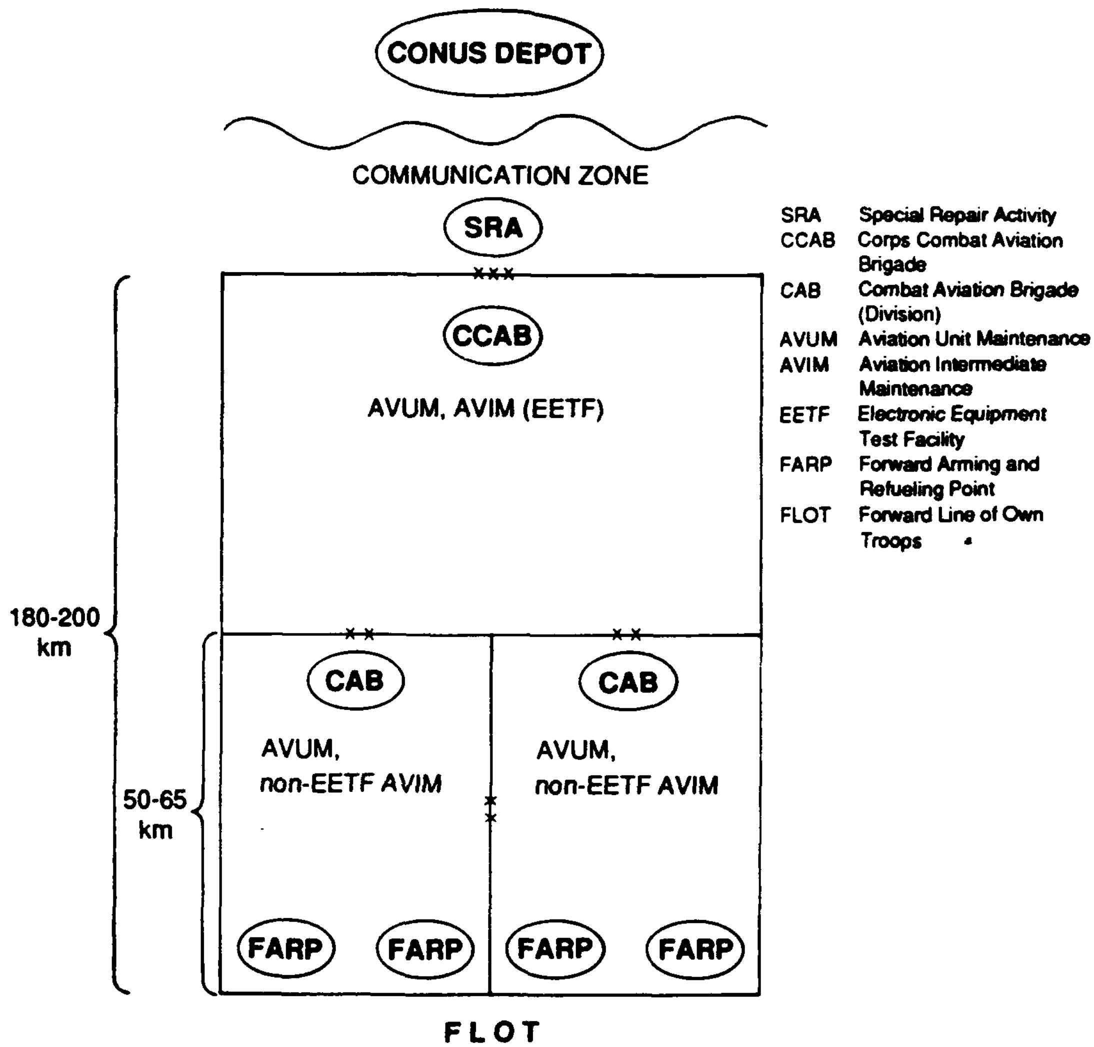

Fig. 10—Schematic Logistic Structure for Apache (one corps)

points (FARPs). Each CAB, at division and corps, has aviation unit maintenance (AVUM) for removal and replacement of LRUs. Carcasses are forwarded to aviation intermediate maintenance (AVIM), and particularly the EETF, located in the corps rear area. Items not reparable at AVIM are sent to depot facilities in CONUS or to SRAs in the theater communications zone. The study assumes a 14-day queue overload policy: the AVIM repair, EETF, will "NRTS" to depot all components in the queue that exceed a two-week waiting period for access to test stands.

Removal Rates

The Army's Unscheduled Maintenance Sample Data Collection for the AH-64 was used to develop data for component reliability. These data were used for the rate of failure, removal rate for LRUs, variance in removal rate, and indenture relationships of systems, LRUs, and SRUs.

Stock Requirements

AH-64 units will carry prescribed load lists (PLLs), authorized stockage lists (ASLs), and war reserve materiel (WRM). The requirements for these sources of spare parts were being developed during the course of this study, and were not available. Dyna-METRIC, the model used in this study, generated stock requirements for this scenario through calculations. The model uses an algorithm to determine the least-cost solution to fill those backorders necessary to achieve a set availability goal. Given the different methodologies used to calculate spares needs, any specific result may differ from Army systems' output. Since we are examining the relative benefits of alternative support structures to maintain the Apache, the relative nature of the comparisons will mitigate any difference and not affect the relevance of our results.

Test Equipment Performance and Availability

Performance characteristics of the EETF were generated from the RAM/LOG data collection on test times, NRTS rates, and test equipment availability. For depot level repair of TADS/PNVS LRUs, data from the Martin Marietta-operated SRA were employed to determine test times, NRTS rates, and manpower demands. In the base case, we assumed the EETF had to have an availability of 12 hours per day, with downtime coming from required maintenance on the test equipment and from the need for biweekly movement.

Attrition

Likely wartime aircraft attrition rates are another source of uncertainty. In our analysis, we assumed that attrition averaged some 3 percent of the fleet per day in the first 10 days of combat, and then declined to less than 1 percent per day for the remainder of the scenario. Damage to repair capability is handled in an approximate

manner in an analysis excursion. Since all AVIM repair capability will be located in the corps rear and all SRAs will be located in the theater communications zone, we assumed they will be relatively safe from attack. However, to examine the relative robustness of each structure, we conducted an excursion where we assume a successful enemy attack destroying 40 percent of AVIM and SRA capability on Day 30 of the war.

Transportation

Transportation data were obtained from the logistics intelligence file. We reviewed these data with other LIF data and with the Uniform Materiel Movement and Issue Priority System (UMMIPS) standards to arrive at the nominal estimates of 21 days order-and-ship time for serviceables and 28 days retrograde time for reparables going to CONUS depots.

In any major European contingency, strategic and tactical transportation will be overloaded. Because most inter- and intratheater transportation is involved with unit movement during this period,[3] we assumed a 30-day cutoff of repair parts, supply, and retrograde to CONUS depots.

THE MODEL AND PERFORMANCE CRITERIA

To evaluate logistics capability, we wanted a model that focuses on a measure of wartime capability such as weapon system availability in the dynamic wartime environment and that includes the known variability of demands that exceed the Poisson distribution variability found in most stock models. The model should also account for the integrated effect of transportation, supply, maintenance, and situation visibility on the availability of the weapon system.

Over the past nine years, RAND (in Project AIR FORCE) has developed Dyna-METRIC to meet these criteria; the model has been extensively used to analyze Air Force needs, as well as some Army problems. Using a multi-echelon technique for recoverable item control, Dyna-METRIC reflects wartime uncertainties and dynamics in an integrated logistics structure with repair and supply at different eche-

[3]See M. D. Rich, W. L. Stanley, and S. Anderson, *Improving U.S. Air Force Readiness and Sustainability*, RAND, R-3113/1-AF, April 1984, p. 27.

lons. We have adapted this model to make it applicable to the U.S. Army. The model allows us to represent rates, test equipment availability and capacity constraints, controlled substitution, repair part indenture, and repair overflows to higher echelons.[4]

Dyna-METRIC can also evaluate the benefits of a prioritizing system, both for repair induction and for distribution. However, the Dyna-METRIC version used in this study was limited in its ability to show the benefits of such prioritizing. The results presented in the next section understate the value of a truly responsive system—one that not only has faster turnaround times for a set of components (such as all TADS/PNVS) but that can discriminate among components at any one time to determine priority of repair and distribution. Our results show most strongly the value of a responsive system in terms of cutting pipeline lengths for critical subsystems; to some degree, they also show the value of an adaptive system that can discriminate among components in a queue.

More advanced versions of the model have since become available that more fully show the advantage of being able to prioritize repair on constrained test equipment and send serviceable LRUs and SRUs to units in terms of where they would do the most good.[5] The more advanced model has been used in follow-on analysis to isolate the benefits of a fully responsive system; that work concludes that such a system would bring benefits even greater than those shown in this study.[6]

Dyna-METRIC can measure capability in several ways. It provides aircraft availability and sorties generated for a given input or, to achieve a desired level of availability and sorties flown, it determines

[4]See Karen E. Isaacson, Patricia Boren, Christopher Tsai, and Raymond Pyles, *Dyna-METRIC Version 4: Modeling Worldwide Logistics Support of Aircraft Components*, RAND, R-3389-AF, May 1988; Raymond Pyles, *The Dyna-METRIC Readiness Assessment Model: Motivation, Capabilities, and Use*, RAND, R-2886-AF, June 1984; and R. J. Hillestad, *Dyna-METRIC: Dynamic Multi-Echelon Technique for Recoverable Item Control*, RAND, R-2785-AF, March 1982.

[5]Dyna-METRIC Version 4 was used in this study. It is an analytic model with some ability to represent constrained test equipment and priority repair but no capacity for showing priority distribution. A new, more advanced version of the model, Version 6, can perform multi-run simulations, more realistically capturing the effects of constraining test equipment; it can also show the value of prioritized distribution.

[6]Patricia M. Boren, Karen E. Isaacson, Judith E. Payne, Marc L. Robbins, and Robert S. Tripp, *An Evaluation of the VISION Execution System Demonstration Prototypes*, RAND, R-3967-A, 1991.

the necessary resources (in terms of stocks) to achieve the goal. This study employs both measures. To compare the cost-effectiveness of alternatives, it fixes an effectiveness measure of 85 percent aircraft availability at high confidence (the 90 percent level)[7] and determines the cost of each alternative to maintain that goal. To test robustness, the model uses as inputs those resources (stock, repair, transportation) needed to achieve a minimum 85 percent availability and measures degradation of aircraft availability in changed conditions (higher demand rates, longer scenario, etc.).

ALTERNATIVE SUPPORT STRUCTURES

Support structure alternatives differently emphasize the three major facets of support: stock, repair, and distribution (including transportation and management information systems). Rapid repair and distribution may substitute for stock, and large piles of spares may make up for deficiencies in work-floor induction procedures, trained repair personnel, and transportation networks. Each facet carries a cost, and the question is how the trade-off between stock and repair/distribution is likely to work out.

This study investigates five alternative support structures, which may be categorized into two types—standard repair alternatives and responsive support alternatives. The first type emphasizes stock and "unsophisticated" repair strategies, whereas the second type reduces stock levels while requiring more demanding types of repair and distribution.

Standard Repair Alternatives

Base Case. The base case assumes that wartime support of the Apache follows the structure the Army has developed to support other weapon systems. Our "base case" structure follows the early planning for supporting the Apache. Currently much of the Apache MEP is supported by SRAs. However, the final decisions for supporting the Apache have not been made and we hope this effort will influence the final structure.

[7]This is higher than Army goals for weapon system availability; on the other hand, this study looks only at MEP availability while considering all other subsystems as FMC. To achieve Army aircraft FMC goals, higher availability of subsystems, like the MEP here, will be necessary.

A standard support structure for the Apache would include an EETF in the corps support area repairing all LRUs configured for EETF support. (One EETF supports 54 aircraft; to maintain 306 aircraft, we employ six EETFs in this structure.) Those LRUs not handled by the EETF would travel through standard Army and service theater and inter-theater transportation systems to a CONUS depot for repair and return to the theater, where their distribution to forward units is determined by requisition priority. In peacetime, repair cycle times through CONUS depots average six months, determined in part by the exigencies of maximizing efficient use of depot manpower. Presumably, depots on wartime footings would do much better than this. Still, with expected total transportation time of 49 days (order-and-ship and retrograde), the turnaround time through the depot is unlikely to be less than 60 days.

The performance of AVIM-level support, particularly the EETF, is a potential major bottleneck in the standard support structure. Virtually all the components modeled in this study first undergo testing at the EETF. If the EETF cannot diagnose the fault, or cannot put it on the test stand in a two-week period, the components will enter the 60-day pipeline to and from the CONUS depot. Thus the viability of the standard system obviously depends on an effective EETF.

Our analysis of EETF RAM/LOG data from Fort Hood suggests that the EETF may not be performing effectively. NRTS rates are extremely high, both from failures in TPSs and from inefficient or flawed testing procedures. In addition, test times, even if diagnosis is successful, are quite long on the EETF; some of the highest demand items, such as the TADS night sensor assembly, occupy the test bench an average of six hours. (See App. C.)

Improved EETF. Enhancing the EETF is one way to improve the standard support structure without making major changes in it. Thus, in an excursion to the standard case, we explore the impact of an upgraded EETF. Improvements in EETF performance can either come about through programmed upgrades in hardware, software, and procedures, or they may happen as the system "gets well"—that is, as technicians become more familiar with its operations and can find means to increase its effectiveness.

Forecasting the extent of EETF improvement is difficult, but based on information from the Army and RAND's experience in studying other kinds of test equipment, we estimate some potentially substantial improvements in EETF performance: 50 percent reduction in NRTS

rates, a 50 percent increase in EETF availability, and a 25 percent reduction in LRU time spent on the test equipment.

Responsive Support Alternatives

In a second set of alternatives, we propose changes in intermediate- and depot-level repair either by moving depot-level repair to the theater for a few LRUs and offloading some workload from AVIM or by enhancing responsiveness of high-tech depot repair in CONUS. These alternatives fall into two types: an enhanced depot and theater-based SRAs.

"Enhanced" Depot. The first alternative seeks selective substantial improvement in the turnaround time in CONUS depot repair of high-technology Apache LRUs. Since most of the cost of meeting Apache availability goals arises from filling pipelines to a depot that, Army data indicate, might require a 60-day turnaround time in wartime, substantial savings can be achieved by selectively shortening the depot leg of the support structure. Adding assured distribution and responsive priority repair would greatly reduce the repair cycle time for depot repair of especially critical items. Given this support philosophy, we estimate that reductions of 20 to 60 days for repair of these critical items may be feasible.

The long turnaround through the depot results from inefficiency in transportation and repair. Lack of rapid assured distribution means slow transit through the various nodes of the standard transportation system and inefficiency in delivery of components to units with the greatest need. The absence of systematized priority repair in the depot adds to these inefficiencies and, while possibly maximizing use of depot manpower, does not lead to maximizing combat capability.[8] In anticipated wartime scenarios, a current slow response depot is not likely to effectively support combat operations. Given the substantial resources in facilities, test equipment, and manpower, there is a strong incentive to design a structure that would bring the depot more directly into the war support effort.

[8]Depots will be able to prioritize in some fashion, even without a management information system like VISION. For instance, depots routinely respond to emergency requests from commanders in the field. However, this type of ad hoc prioritization cannot best exploit limited resources, nor can it allow the depot to evaluate how its actions increase overall weapon system capability.

Given less reliance on large stockpiles of spares, fast responsive support must efficiently turn around selected carcasses. It must strive to avoid the usual bottlenecks that characterize most support structures, be they in the transportation nodes or in the repair facilities, and with few extra LRUs to spare, it must ensure they arrive at locations where they are most needed. Thus, the elements of an enhanced depot alternative would include: (1) assured rapid theater transportation and distribution for a limited set of high-technology LRUs (and possibly SRUs) critical for weapon system availability; (2) a similar resource for moving these LRUs over the ocean and to the CONUS depots; and (3) a modified management structure in the depot and in the workshop to induct, repair, and send out the high-priority LRUs more effectively and rapidly.

As described later, the small size and volume of this limited set of components make specialized and rapid transport cost-effective. We envision a network of small fixed-wing aircraft (or possibly rotary-wing) that would provide timely pickup and delivery of high-technology components from division or corps. Also because of the small payloads involved, over-the-ocean and intra-CONUS transportation may be carried out by narrow-body, unmodified Civilian Reserve Air Fleet (CRAF) aircraft. Depot repair may be made more efficient by changing management and procedures. An ongoing RAND research effort to create a depot work management information system, the Readiness-Based Maintenance System (RBMS),[9] is studying the feasibility of designing and implementing a management information system to increase the effectiveness of depot repair and distribution actions. This same system may be employed in the depot and theater to most effectively handle distribution of serviceable components to units.

SRAs. A second set of alternatives for fast, responsive support calls for using SRA facilities to handle repair in wartime. In contrast to a changed depot structure, SRAs have extensive and increasing real-world experience behind them, which means we can fairly accurately estimate both capability and costs.

An SRA is a small facility with a minimum of overhead that can effect especially rapid turnaround by specializing in a small number of highly critical items. The Army currently uses SRAs to repair

[9]The RBMS system was originally developed at RAND under the name VISION (Visibility of Support Options). See the discussion of VISION in App. B.

TADS/PNVS LRUs (and some SRUs). The facilities are located outside Fort Hood, Fort Rucker, Fort Bragg, and at Coleman Barracks to support USAREUR Apache assets. The closeness of the facility results in minimal transportation time and avoidance of the usual cumbersome military transportation channels. The focus on a limited set of items reduces the need for specialized equipment and wide varieties of skill and training. The limited number of bases that depend on these facilities and the constant communication between base and SRA allows a minimum of managerial overhead. Thus, SRAs can be small even while supporting large numbers of aircraft (the SRA at Fort Rucker is located in the rear of a laundromat) and can achieve rapid turnaround.

This study assumes an SRA with a six-day repair cycle time. Such a schedule requires a specialized theater transportation/distribution network devoted to moving a limited set of Apache LRUs from AVIM to the SRA and back. With longer-range fixed-wing aircraft (such as the Shorts Sherpa), the SRA may be located well into the communication zone; for the European theater, this might mean placing the SRA in Belgium, the Netherlands, or even Great Britain and Spain, although the greater distances will require relying on a RBMS-like management information system.[10] Alternatively, the SRA could be located in West Germany, out of the range of most weapons of potential adversaries, and could be serviced by rotary-wing aircraft already owned by the Army, such as the UH-60 Blackhawk.

TADS / PNVS SRA. In the first SRA alternative explored here, all TADS/PNVS LRU repair is offloaded from the EETF and sent directly to two SRAs, each serving one corps. With a smaller load, no improvements in the EETF are included. TADS/PNVS LRUs that are not currently testable at the EETF or at currently operating SRAs would be repaired at CONUS depots and would follow the standard 60-day repair cycle; these include mostly laser-related devices. The size of the SRA facilities is based on workload demands, but we antic-

[10]As repair sites are further removed from combat units, a management information system is needed to direct repairs to the priorities of the force because repair is out of "earshot" of commanders and the maintenance crews located forward. Also, as workload is consolidated rearward and made more efficient by smoothing the workload drawn from forward units, a system like RBMS is needed to manage the resulting queues. Given unavoidable pipeline times, RBMS also will be needed to look ahead to future unit needs and to prioritize repairs and supply actions for proactive logistics support.

ipate five sets of TADS/PNVS test equipment, which would offer the potential for spare capacity.

Extended SRA. Several critical LRUs of the Apache MEP are not handled either at the EETF or in a TADS/PNVS SRA, yet they exhibit high demand rates and are too costly to overstock. They include, for example, LRUs from the IHADSS (the helmet display unit and the sensor survey unit), the FCC (although it is anticipated that software for EETF-repair will be developed in this case), and the Heading and Attitude Reference System. Currently, these LRUs are fixed only at depots, but such delayed repair in wartime is likely to prove costly in aircraft availability.

Thus, a second SRA alternative proposes extending SRA-type repair to other "high burner" items. Although their repair may be collocated with the TADS/PNVS SRA, they would require different types of test equipment, as well as different personnel, if cross-training is not feasible. As in the previous case, this alternative assumes a specialized transportation and distribution system, and the only difference is the increase in SRA capacity to handle the additional items.

4. PERFORMANCE OF SUPPORT ALTERNATIVES

This section addresses the analysis of the alternative support structures in terms of two criteria of merit. First, in terms of *cost-effectiveness*, it seeks to measure the total cost of a support structure attempting to achieve a goal of availability, given a stable set of conditions (scenario, removal rates, etc.). Second, to measure *robustness* of support, it applies those resources against an unpredictably variable wartime environment. In the first case, the aim is to ascertain which support structure offers the least cost in meeting the performance goal; in the second, given that cost, it seeks to determine which structure suffers the least performance degradation in the face of unexpected conditions.

ANALYSIS OF COST-EFFECTIVENESS

In the cost-effectiveness analysis, constant effectiveness of support structures is assumed; that is, each support alternative delivers constant availability of aircraft (set in this study at 85 percent with 90 percent confidence). The only distinction among the alternatives, then, is the cost of achieving that level of performance. This subsection details the cost of the various alternative structures.

Figure 11 shows the results of the cost-effectiveness analysis. It illustrates the total cost for each support alternative to maintain constant effectiveness of the Apache fleet in terms of fully mission capable aircraft.[1] It covers the cost for supporting an extended scenario with set flying requirements for each of the days and a predetermined level of attrition. It does not take into account the variability of a wartime scenario, which will be taken up later. The question addressed here is: for a standard set of conditions and a demanded level of performance, how do the costs of support alternatives compare?

[1]"Fully mission capable" is defined as not missing any of the LRUs modeled in this study. We do not take into account the possibility of "partially mission capable" aircraft. For some missions, of course, the Apache can fly without a fully capable MEP—antipersonnel missions in clear flying weather, for example. However, it is anticipated that the antiarmor mission will be the main driver of Apache workload, and night capability is a major advantage of the Apache in almost all scenarios. Missing or degraded parts of the MEP will make these missions difficult or impossible to accomplish.

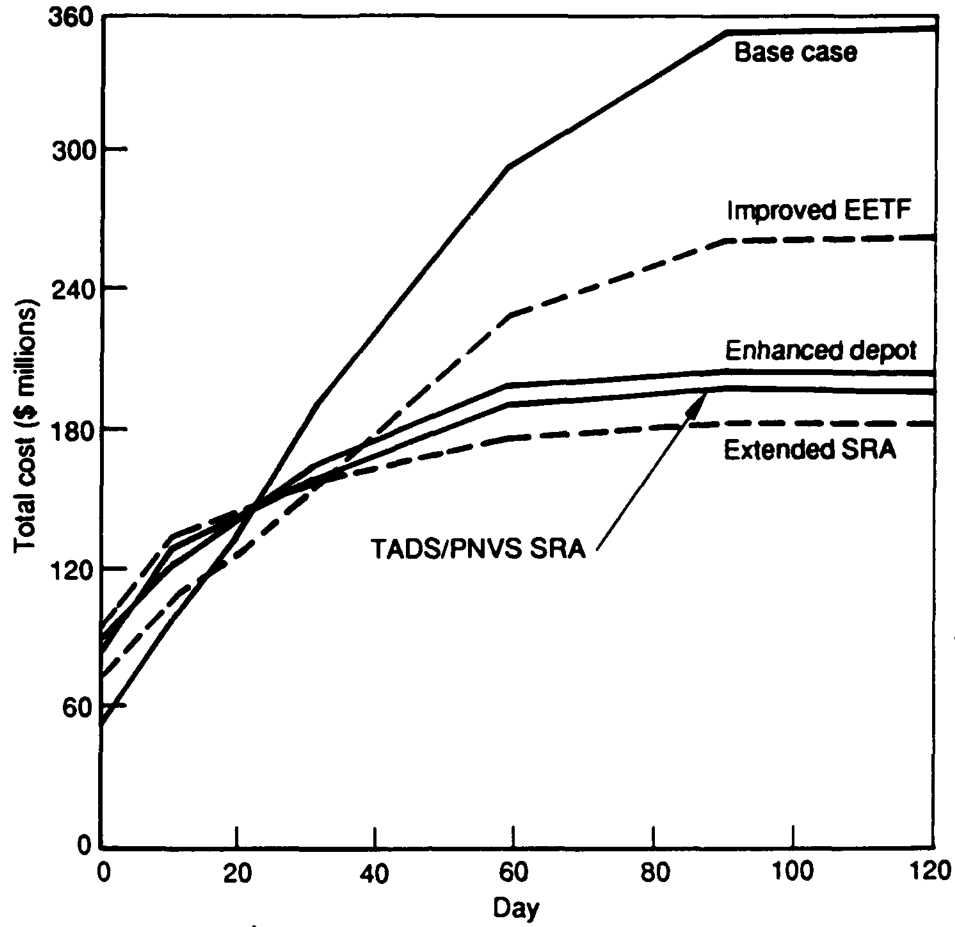

Fig. 11—Costs of Alternative Support Structures at Constant Effectiveness

The Dyna-METRIC model allows continual purchase of stocks to make up for those filling pipelines throughout the scenario. Thus, one can vary the purchase of stocks as they become needed during the scenario. Although this is unlikely to happen in reality (stocks not bought before the war are unlikely to become available within 120 days), it does allow us to compare alternative effectiveness at different points in the scenario.

In the analysis, we begin with zero stock and a fully costed repair and transportation/distribution structure, shown as the intercept in the figure. The increasing costs over time are then the incremental stock needed to stabilize pipelines as they fill. Although the scenario shown extends to 120 days, the cost of supporting the force reaches its

maximum earlier, by Day 90, when pipelines to and from CONUS depots tend to stabilize.

Of the alternatives, the base case is by far the most expensive over a 120-day scenario; especially after Day 20, its costs exceed all other alternatives. The greatest part of the cost of this alternative lies in stock. Low EETF performance penalizes the standard repair structure. High NRTS rates and long repair times, leading to long queues, result in large numbers of LRUs being sent back to depot that were to have been kept in theater. Improving the EETF then offers the potential for significant costs savings.

As the improved EETF curve shows, improving EETF performance can cut costs by over $100 million. However, few additional gains are likely to be made beyond this; to improve EETF performance further would require fairly significant cost and, given the much smaller queues now at the EETF, would not tend to be cost-effective.[2]

The three alternatives emphasizing fast responsive support over large amounts of stock appear to be far more cost-effective. All fall in the range of $185–$205 million to support two corps of Apaches through the scenario. Initial costs for repair structure and transportation resources are higher than in the standard structure, but savings in stock for the reduced pipeline lengths more than make up for these differences throughout the scenario. Although the model results show differences in performance among the three responsive support alternatives, the differences are not great enough to provide a basis for choosing among these alternatives.

Table 2 shows the breakdown of cost elements for each of the alternatives. Costs for each alternative are divided into the functional areas of stock, depot-level repair, intermediate repair, and transportation/distribution. The method used is marginal costing, which means we show only the marginal cost in an alternative for providing some logistics support. Otherwise, if the support is the same throughout the alternatives, no cost is shown. For example, while all alternatives have EETFs, only the improved EETF and the enhanced depot alternatives assume EETF performance has been improved. Thus, costs

[2]Increasing the number of improved EETFs by 50 percent would probably not be cost-effective. The amount of stock needed to fill pipelines would be reduced by $50 million, but the cost of increasing test stand capacity would be even greater (three EETFs for $30 million, plus $12 million for upgrades, and approximately $30 million for operating and support costs over a 20-year life cycle).

Table 2

Cost Elements of Support Alternatives
($ millions)

Alternative	Stock	CONUS Depot	Theater SRA	EETF Upgrade	Theater Transportation	Total Cost
Base case	301	44				345
Improved EETF	185	44		25		254
Enhanced depot	114	44		25	21	204
TADS/PNVS SRA	117	10	57		21	205
Extended SRA	94		72		21	187

for enhancing intermediate repair (at the EETF) are shown in these alternatives, but not for the others. Similarly, there is theater transportation in all alternatives, but only in the responsive support alternatives is a specialized, rapid system assumed and costed; otherwise, standard theater transportation is assumed, with no cost shown.

The competing support alternatives make trade-offs among the three logistics resources—stock, repair, and distribution. The base case makes by far the largest investment in stocks—over $300 million to support two corps of Apaches. The improved EETF alternative substitutes a $25 million upgrade of intermediate test equipment and is able to realize over a $100 million savings in total support costs. The responsive support alternatives are able to greatly reduce the amount of stock they need—down to under $100 million in the case of the extended SRA. In its place, they put somewhat more expensive depot-level repair (in the case of the SRAs) or upgraded intermediate repair (in the case of the enhanced depot), and all these alternatives rely on a dedicated, or at least assured, distribution system. Appendix A documents the costs found in Table 2.

ANALYSIS OF ROBUSTNESS

As mentioned earlier, the level of uncertainty from wartime scenarios means the Army must create a support structure with enough flexibility, or robustness, to withstand some of the greater surprises to be found in combat. Although logistics planning usually is based on some type of anticipated scenario, real wartime is unlikely to pro-

ceed according to planned flying and attrition rates or removal rates. Beyond simple cost-competitiveness, any desirable support structure must continue to perform cost-effectively when war turns out more demanding than the scenarios predicted.

Three Tests of Robustness

One simple way of testing robustness is through unexpected increases in demand rates. Many of the surprises in war can be reinterpreted as equal to an increase in the removal rate of LRUs. Lower attrition than expected will increase the number of total removals; destruction of spare LRUs or of test equipment will increase the demands on the remaining test equipment; the removal rate itself may be higher in wartime than peacetime experience leads one to believe.[3] Thus, we test the robustness of the five alternatives by applying a 50 percent increase in demand rates over what was planned for and bought to support.[4]

A second test of robustness assumes greater enemy ability to damage repair facilities than expected. The intent here is to evaluate the risk involved (added vulnerability) in moving depot-level repair for critical items to the theater. One argument against theater depot-level repair, here represented by the SRA alternatives, is increased vulnerability to enemy attack and the possible unreliability of civilians working in a combat environment. Putting the SRAs back far enough, possibly in Great Britain or Spain, may deal with these possible shortcomings, although this may lengthen turnaround time and thereby increase system costs over what we have shown. The threat to SRAs even in the western part of Germany is difficult to measure; given the small size of the SRAs and the lack of immediate benefit to

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[3]We have found that variability of removal rates tends to be larger in periods of intense activity; see R-3673-A, pp. 15ff. This may result in part from increasing rates of misdiagnosis in these periods; other RAND research has found jumps in occurrence of NEOFs in high-activity situations.

[4]This study used removal rates from the sample data collection. Based on peacetime data, these measures may understate the level of demands, even on a per-hour basis, likely in war. RAND research carried out at the Army Aviation Center, Fort Rucker, Alabama, found that removal rates in combat-like missions (gunnery and night-flying) tended on average to be 50 percent higher than removal rates for all mission types (daytime included) averaged together. We apply that 50 percent increment here in a blanket fashion to all LRUs. (This actually understates the dilemma as, for certain LRUs, removal rates in war may be increased up to 400 percent.) These and other results of the Fort Rucker analysis will be forthcoming in a future RAND Arroyo Center publication.

the adversary of attacking them, it may be more likely that they would be destroyed in an enemy attack by accident than by design.[5] This robustness test evaluates the ability of support structures to deliver combat effectiveness when enemy action destroys 40 percent of theater repair on Day 30. (For non-SRA cases, this means the EETF; for the SRA cases, this refers to SRA capacity only.)

Another form of robustness is required when war continues longer than is expected or, at any rate, longer than one expects to be able to afford. In the coming years, Army budgets are likely to be severely constrained, which means that trade-offs will have to be made and goals may have to be reduced. While the previous analysis has estimated the cost for supporting a 120-day scenario, it is likely that priority will be given to the first 30 days of the war. Thus, in the last test of robustness, we calculate costs for alternative structures to meet an availability goal for a 30-day war and then examine the robustness of each alternative—its ability to degrade "gracefully"—if the war extends beyond 30 days.

Test 1: Higher Demand Rates. In this test, each alternative is provided with the inputs costed at the amount shown in Table 2; with the given scenario, those resources would provide a minimum of 85 percent aircraft availability (at 90 percent confidence) throughout the 120 days. Figure 12 shows how far performance would degrade at the higher than expected demand rate. The column on the far right illustrates the "robustness cost"—the cost, in additional stocks, that would have to be purchased at the higher demand rate to maintain the 85 percent availability goal.[6]

Even at the high initial cost to support the standard scenario, both the base case and that with the improved EETF alternative perform

[5]As noted, this analysis has used a Central European scenario to illustrate the benefits of a more robust and responsive system. We do not believe it would be applicable only to such a scenario. The ability to support forces with remote repair opens up the possibility of providing logistics support to forces that may even be half the globe away (if rapid and assured transportation can be found). Similarly, the point about SRA vulnerability is also applicable in other scenarios—especially those where the division between "front" and "rear" may be even more ambiguous than in the European case.

[6]This "robustness cost" is meant more as a metric than as a policy recommendation. Because wartime removal rates are unpredictable, it is not clear that even buying this large amount of stock will afford sufficient protection against uncertainty; further, this does not take into account other strategies to deal with uncertainty—buying more EETFs, SRA test sets, or more transportation resources.

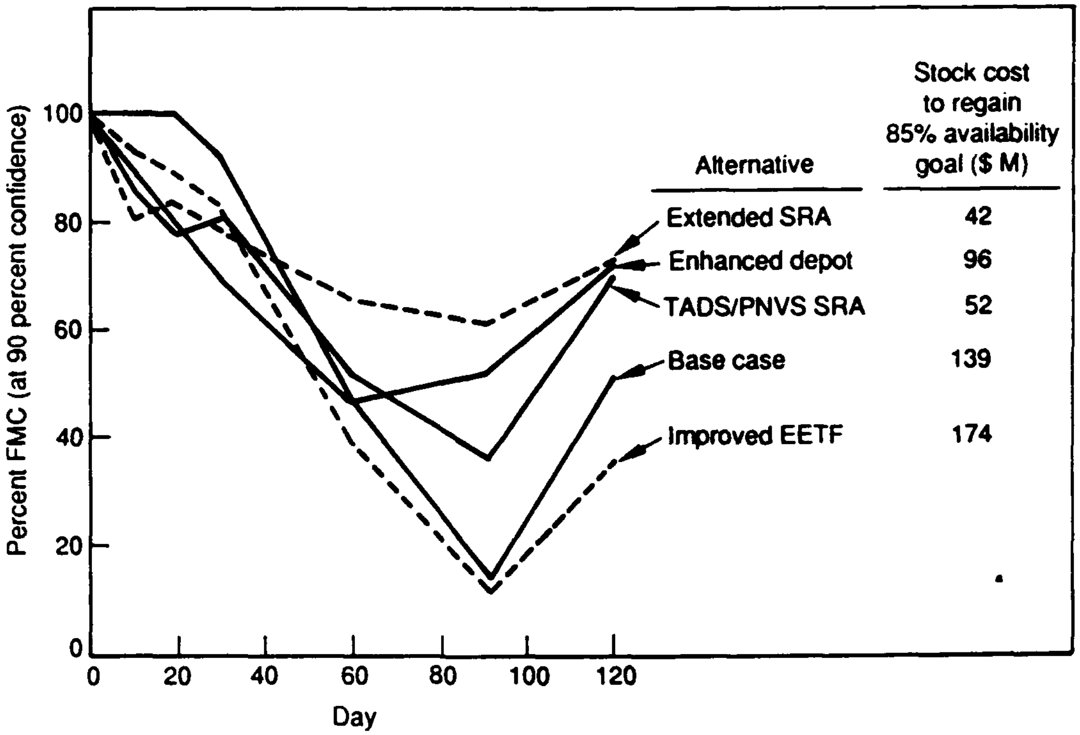

Fig. 12—Impact of Higher Than Expected Demand Rates on Apache Availability

quite poorly. Availability in both cases drops below 60 percent after Day 40, and bottoms out below 20 percent by Day 90. The "robustness" penalty is especially high for these two cases—$139 million for the base case, and $174 million for that with improved EETF performance.

In the improved EETF alternative, extra stock is sacrificed for greater EETF performance, at a substantial cost savings. (See Table 2.) However, this advantage is overwhelmed by the additional demands; the number of high-priority carcasses demanding repair is so great that the advantage of a faster EETF is negated. The performance of this alternative actually falls below that of the base case, as the curve shows, because it has less stock available to fill back orders and yet cannot turn them around in local repair.[7]

[7]An analogy with improving ski lift operations may help clarify this. Improving one part of a ski lift—say ticket punching—will not help much if it does nothing about other

This robustness test highlights differences among the responsive support alternatives that were not apparent before. Each maintains a level of performance well above those of the base case alternatives, yet the extended SRA alternative clearly degrades least, and the enhanced depot alternative appears slightly better than the TADS/PNVS SRA. Also, in terms of "robustness penalty" costs, the extended SRA is again clearly superior; in terms of the other responsive alternatives, the enhanced depot is considerably worse than the TADS/PNVS SRA, despite somewhere better availability performance.

These differences are explained by combinations of pipeline lengths and by which critical LRUs are given priority repair. The TADS/PNVS SRA delivers less aircraft availability because its slice of the workload is narrower. It repairs only TADS/PNVS LRUs, whereas other LRUs (such as the HARS and those in the IHADSS) are sent into a long pipeline to the depot. The responsive depot, on the other hand, is much broader in its repair capability, but it accomplishes it at the cost of a 20-day (versus six-day at SRA) repair cycle time. Despite worse aircraft availability, the "robustness penalty" of the TADS/PNVS SRA is lower than that for the fast depot because its workload includes the higher-cost components; those LRUs it does not handle, such as the IHADSS helmet display unit, typically cost less than $10,000. So it might be wise to lay in extra stocks of these items needed to cover unexpected emergencies; with the enhanced depot, which does not discriminate between $5000 LRUs and $160,000 LRUs, such an insurance policy would cost double.

By contrast, the extended SRA gets the best of both worlds. It is constructed to repair all high-burner components, and it produces relatively more combat capability when demands increase (since it sends few items back into the long depot pipeline). And the LRUs that are sent back to depot tend to have lower unit costs. The most expensive items are fixed at the SRA and, with a six-day turnaround, have small impact on the "robustness penalty."

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other potential logjams. Skiers may get tickets punched faster, only to have to wait for a seat on a still slow-moving lift. In the improved EETF alternative, only one facet of the overall support process was enhanced, so that when demands grow too large again, and overwhelm the improved EETF, carcasses must overflow into what is still a 60-day pipeline. Improving the support structure in such a piecemeal fashion may yield gains, but only in a narrow range of conditions, as in the original scenario. As demonstrated here, piecemeal reform is fairly easily overwhelmed, and can often yield no real overall advantage at all. Effective robust structures need elimination of *all* potential logjams.

Test 2: Impact of Damage to Repair Facilities. The SRA alternatives derive their advantage from having a fast turnaround time that, in turn, depends on being in the theater itself. As a result, the robustness of an SRA alternative is somewhat uncertain. Certainly, compared to a depot option, the SRA alternative puts depot-level repair at more risk from enemy action.

However, it is difficult to evaluate the level of that risk. First, SRAs would be small operations with very little signature and, thus, hard for threat forces to target. Second, they could be placed far enough in the rear (as far as England or Spain in the European scenario) to make any enemy attack on them highly unlikely. Third, it is not clear that the enemy would wish to specifically target operations like the SRA, at least compared with other high-priority targets, since the benefit of doing so would not immediately be seen on the front line.

Nonetheless, facilities in theater are likely to be more at risk than CONUS depot facilities, even if only from accidental or "lucky" enemy hits. Of concern here is the level of risk to combat performance if SRAs prove too vulnerable. Figure 13 shows the effect of successful enemy attacks on theater-level repair on aircraft availability. It assumes the support structure cost shown in Table 2 is fully paid, with a minimum availability level of 85 percent, assuming no unexpected changes. The "unexpected change" here is an enemy attack on Day 30 of the scenario that destroys 40 percent of theater-level repair.[8] All carcasses in retrograde are assumed to be diverted to the remaining theater repair capability.

As before, the improved EETF alternative fares worst. Enhancing one element of the support structure, it appears, leaves the performance of the entire structure highly sensitive to changes.

In contrast, the base case and the responsive support cases, including those relying on theater SRAs,[9] all perform about the same. Losing 40 percent of repair capability has some effect on the SRA efficiency, but not a great deal: instead of maintaining at least 85 percent availability, the SRA alternative allows that figure to drop down only to 75 percent. By exploiting priority repair procedures, and having

[8]In cases with no SRA, this refers to destroying 40 percent of EETF capacity; in the SRA cases, it refers to destruction of SRA capacity only.

[9]The performance of both types of SRAs is identical, and they are shown on one curve.

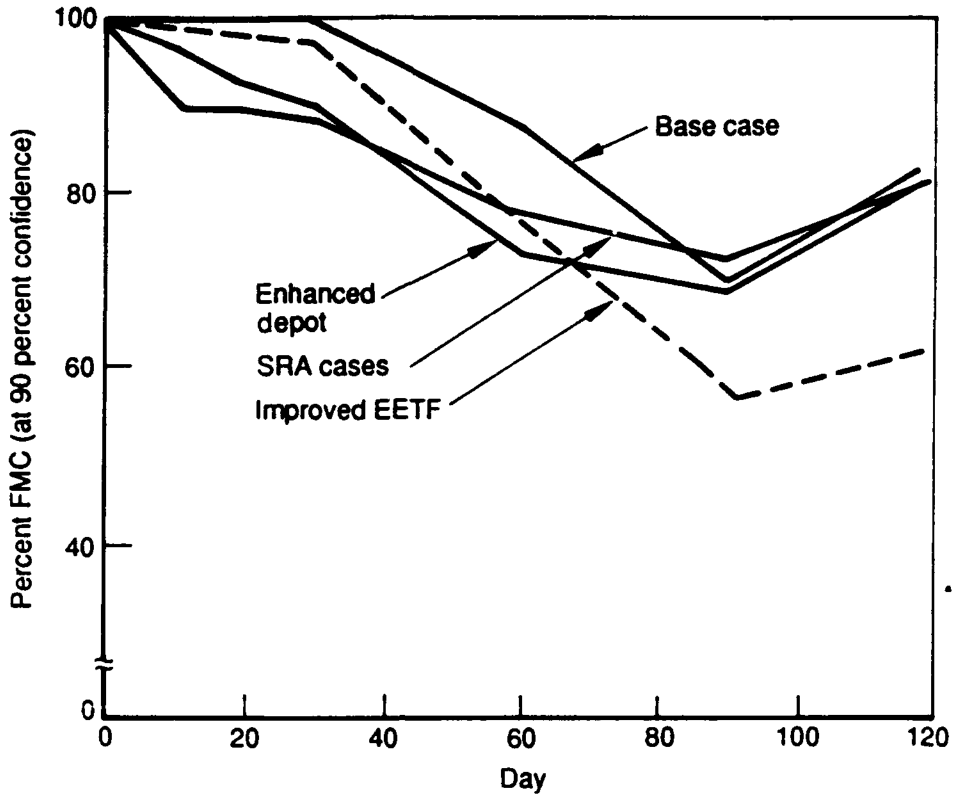

Fig. 13—Impact of Test Stand Damage on Apache Availability (40 percent of capacity destroyed on Day 30)

some extra capacity to begin with, the SRA alternative is able to minimize the cost in performance of losing capability.[10]

Test 3: Supporting a 30-Day Scenario. Figure 14 shows the result of the short scenario analysis. It presents total costs to maintain a minimum 85 percent availability for a 30-day period for each support alternative.

The figure provides two pieces of information—total cost and risk reduction. The column on the right-hand side shows the total cost for

[10]The original cost estimate for the SRA alternative was made with an eye to giving it extra capability; five sets of test equipment were more than were needed for the baseline scenario.

achieving the availability goal over 30 days of combat.[11] Apparently, there is no real difference in cost among the alternatives; such differences as do appear are almost certainly "in the noise."

However, looking beyond cost, there is the criterion of risk reduction. Having anticipated only a 30-day war (and bought resources for that length of time), one is at some risk if the war goes beyond that length of time. What is the level of risk? The figure shows that the standard repair alternatives once again are most sensitive to the initial assumptions; they show no robustness to handle these unanticipated demands. The more narrowly constructed SRA also performs poorly, since it is understocked in those critical and high-demand items it does not repair.

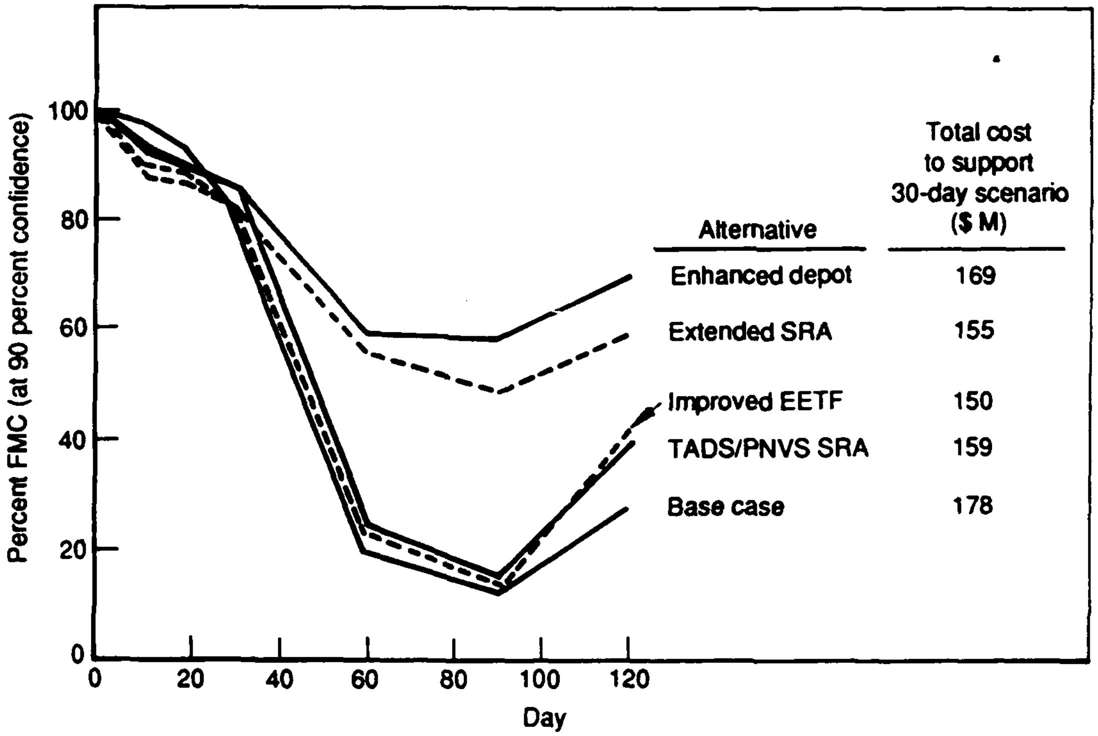

Fig. 14—Cost Benefit of Alternatives to Support a 30-Day Scenario

[11]The reduced costs come solely from savings in stock. Repair structure and transportation are not reduced as we assume intermediate- and depot-level repair will still be needed to support peacetime flying.

The other two responsive support alternatives perform much better against these unexpected demands. Because of its broad base of repair, an enhanced depot clearly offers the greatest insurance against a longer war even at low cost. Sacrificing stock penalizes availability less if the depot capacity to turn selected carcasses around is only 20 days away. The extended SRA also performs appreciably better than the other cases (apart from the enhanced depot), because it is built to handle all high-priority items; however, the lack of spares, combined with 60-day turnaround for nonpriority items, yields a somewhat lower level of combat performance.

5. CONCLUSIONS AND FUTURE DIRECTIONS

CONCLUSIONS

This study has evaluated the ability of several support alternatives to cost-effectively provide high combat availability for the AH-64 Apache attack helicopter. It considered the current type of Army support structure for high-technology components, along with some potentially useful improvements to that structure. It also looked at a class of alternatives emphasizing a philosophy of "responsive support," which trade off large amounts of stock for dedicated transportation and rapid turnaround of critical items at depot-level repair. Specifically, the study examined repair facilities in the theater (SRAs) and an enhanced depot system in which the depot base in CONUS would be made effective enough to support wartime operations in theater even in a relatively short war.

The study found the standard support structure wanting and the responsive support alternatives superior. In terms of cost and "robustness"—the ability to handle the unexpected demands of wartime with least degradation of performance—the responsive support alternatives examined here offer a means for providing cost-effective support of the Apache in a variety of conditions. Our research substantiates the conclusion from a previous RAND effort on supporting the M-1 tank—"the Army must increase the *responsiveness* in its logistics structures or face a loss in combat capability."[1]

Adding high-technology subsystems to Army weaponry brings undeniable benefits in combat lethality and survivability, but it also brings serious problems for sustainability. Without substantial changes in philosophy and doctrine, the Army may find itself in a combat situation with weapon systems that do not work effectively, despite their vaunted capabilities.

ISSUES IN CREATING A MORE RESPONSIVE SUPPORT SYSTEM

Building a more responsive support system is certain to be a complicated and fairly extended task. The next few paragraphs lay out a

[1]R-3673-A, p. 42.

conceptual structure of the major issues involved, primarily including:

- Supporting currently fielded high-tech subsystems;
- Incorporating emerging Army support systems;
- Developing the necessary management tools to make responsive support work;
- Building proper, cost-effective support for the non-high-tech parts of Army systems; and
- Modifying support systems to handle the different needs of future weapon systems like the Light Helicopter.

Support for Current High-Tech Subsystems

We have argued here that for types of critical components that meet certain criteria (high cost, difficulty of repair, uncertain demand, easy transportability), a responsive support structure is cost-effective. The core of such a system is that it substitute rapid repair and fast, assured transportation for the previous reliance on large stockpiles of spares to cover long pipelines. (It is also based on having more sophisticated management systems, discussed below.) Exactly what the outlines of that responsive structure should be, however, opens up various possibilities:

Exploitation of Current Intermediate Test Equipment. The Army has made a major investment in various forms of intermediate test equipment, such as the EETF for the Apache, which have not always performed up to expectations. In many cases, it may be that an SRA alternative, with simpler test equipment and better skilled technicians located in echelons above corps (EAC) or even CONUS, may be a more effective alternative. However, it is not clear that the Army has been able to exploit the full capability of these systems. The Army may be able to better exploit these systems by using a different concept of operations for them—including location farther to the rear, a more controllable working environment, better trained and utilized personnel (though not as expensive as would be found in SRAs), and a different set of procedures and policies for operating the systems.

Location of SRAs. We have viewed the SRA more as a type of facility that can do fast, responsive repair than as something identified as located in a particular echelon. The SRA could be located in any

number of places, depending on the structure of Army forces, the availability of resources (such as lift), and the kinds of expected contingencies. Corps-level (or smaller) contingencies might argue for relatively small SRAs that might deploy with these units. The SRA might be made "modular" to fit the needs of the contingency: austere support packages for short durations (or to cover the period until pipelines elsewhere can be connected) or fully developed SRA capability to provide sustained local support. One means of giving a robust kind of deployability is to locate SRAs on board ships. Alternatively, SRAs could support deployed forces from CONUS locations. The benefits of a CONUS location are obvious—near invulnerability, no time loss from deployment—as are the possible complications, especially the time to transport carcasses and serviceables over long distances and the possible disconnect between deployed units and the repair facilities supporting them.

A CONUS-based SRA system would tend to blur the distinction between SRA and Depot Support Command (DESCOM)-managed depot assets. Conceivably, these SRAs may be located within the facilities of Army depots themselves. As mentioned above, the SRA is a concept of operation rather than a physical location. It is small and flexible, it has a minimum of overhead, it eliminates cumbersome supply and warehousing procedures, and it seeks other forms of efficiency than, for example, maximization of manpower use. Thus, such a facility could be anywhere, including in the depot. (Parts of the depot could be reconfigured as an SRA.) The key is to understand that not all parts of a depot need work by the same methods and, therefore, follow the same procedures. For certain items (e.g., cheap oil pumps) or certain types of repair actions (e.g., scheduled overhauls of transmissions), the general type of depot setup as exists today may be quite adequate and in need of no major revision. But other parts of the depot system might operate with different rules (for example, with different measures of employee performance). Here, the emphasis would be less on widgets produced per man-hour and more on overall contribution to weapon system availability with minimum reliance on spares in the pipeline.

There are two outstanding issues. The first, better communication between the depot SRA and the user, will be addressed below. The other is fast, assured transportation, which is discussed in App. B. Fast, assured transportation is not solely an Army problem (e.g., strategic airlift is the responsibility of the Military Air Command), but it is in the Army's interest to define and emphasize the priority

items must have for transportation. There are ways—such as through modeling—by which the benefits of fast movement for combat effectiveness can be shown, and the Army needs to make better use of these tools. It also needs to appreciate the qualities of smallness. As argued earlier, moving high-tech LRUs and SRUs is a trivial enterprise in weight and cube terms; truly, the task gets lost in the noise of the staggering problems of transport the Army normally faces. Yet by that very token it should not be ignored; it should be made a high priority to determine how these tiny, trivial payloads should be moved the fastest way possible.

Incorporating Emerging Army Support Systems

The Army is creating new tools and structures that could play a major role in more responsive support systems. Two of them are of special interest, the Integrated Family of Test Equipment (IFTE) and the Electronics Maintenance Company (EMC). The IFTE is a common piece of test equipment in three parts: a contact test set for unit-level screening; an intermediate test station, potentially mounted on a van or truck; and a depot-level tester of LRUs and SRUs. It has the potential for wide-ranging commonality for testing and fault-isolation on Army electronic components, with a goal of servicing over a score of Army weapon systems and possibly thousands of LRUs and SRUs. The EMC is a proposed change in doctrinal structure that could exploit IFTE-like capabilities. It would be a maintenance unit devoted to testing and repairing electronic components from any weapon system, with a possible location at the division, corps, or conceivably EAC.

Both ideas offer major advantages in terms of economies of scale, redundancy, and flexible support for the Army. At the same time, without the elements of a more responsive system, these capabilities may not be fully exploited. The wide-ranging nature of the IFTE and EMC would seem to demand some sort of remote repair, located fairly far back from the users they service. If located too far forward, these precious resources may become vulnerable to adversaries' attacks; not only would they lose valuable repair time because of having to move too frequently, they would also be unable to exploit the advantages of prioritizing backlogs of work (for example, being able to batch process and prioritize repair at the same time) because they would lack the scope to deal with many weapon systems from many units at any particular time. Yet if they are remote, as argued above, they can be

made truly effective only by having the components of the new system envisioned here: fast repair turnaround with a minimum of overhead; fast, assured transportation connecting repairer and unit; and asset visibility and the management system to exploit that kind of visibility.

Developing Management Tools

The sine qua non of the responsive support system is a new type of management system for Army logistics and the data systems that will give these systems the asset visibility and status they need to work. We have referred in this report to systems that perform portions of this function, like RBMS, which is being developed at RAND. Unfortunately, because of model limitations it was not possible in this analysis to isolate and highlight those benefits. However, other research performed at RAND has spotlighted the advantages of these new management tools. That research has emphasized that, while RBMS provides decision support aids for the logistician and does not determine what actions he or she *must* take, tools like RBMS, along with attendant data systems, can lead to an overall increase in weapon system availability, can help resolve the problem of imbalances of resources among weapon systems that compete for shared repair facilities, can act in a proactive manner to meet commanders' goals for weapon systems availability by sending supplies to units that need them most when they need them most, and can be constructed to "degrade gracefully" by compensating for failures of the data systems in the confusion of war.

The goal of these management changes is, in the words of the commander of the Army Materiel Command, to create a truly *seamless logistics system*—a system in which the logistician can understand the operational status of weapon systems, can anticipate requirements, can look at availability rates, can know what components are causing problems, and can then react in near real time by facilitating the supply of serviceable components.[2]

To gain the advantages of such a seamless logistics system, the Army must make three main adaptations. First, it must build the weapon system-based data systems that provide asset visibility, weapon sys-

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[2]"General Tuttle Talks with *Army Logistician*," *Army Logistician*, January–February 1990, pp. 33–34.

tem status, resource availability, and other necessary components for making informed logistics decisions. This requires better communication between commanders and logisticians so the latter can better make the proactive decisions that will help him support the commanders' goals. The second requirement is to develop, adapt, and implement decision support systems, such as the RBMS tool, to process those data to help the logistician make decisions about such things as prioritized repair and distribution. This involves more than buying hardware, developing software, and automating data for input; it involves the Army determining how to use these systems and what policies, procedures and—indeed—values it is willing to change to adopt a new system and style of management. This change in the Army way of doing business with regard to logistical support is the third, and greatest, adaptation required of the Army. It means, for example, ignoring previous measures of performance—number of repairs per man-hour, maximization of ton-miles in using transportation—to accomplish a seemingly more abstract goal, such as an increase in overall probability of making an availability target. It means that the logistician will not always be able to support customers in quite the personal style that has often proved valuable—that instead, in looking with a wider perspective and larger goals, he may have to inform those asking for help that others have higher priority, based on all the information available. In sum, the basic way of doing things for logisticians will be changed, in ways great and small, by adopting these new systems.

But there may be no alternative. The Army is facing a world in which it will face widely ranging and unpredictable responsibilities yet will have fewer resources to carry out its job. This smaller Army is likely to rely even more on these difficult-to-maintain high-tech systems, despite their ever-increasing price tag. Information, and the exploitation of that information, is the "cheap" alternative to paying more money for increasingly expensive resources or to reducing goals themselves because those resources are so scarce and costly.

Supporting Low Technology

Because of the criticality and support problems of high-tech subsystems, bold new approaches are justified. This does not mean, however, that the Army must reinvent the way it supports *all* components. A certain amount of "stovepiping" is unavoidable, and the obvious division is between high-tech electronics and low-tech me-

chanical systems. It is not clear, for example, that the kind of intensive management of high-tech components described above would be cost-effective for low technology, because the vast number of low-tech items, and their generally low unit costs, would make any such system cumbersome and not particularly valuable in adding to combat capability. Given the uncertainty of demands even for the low-tech systems, the best alternative may simply be stocking sufficient quantities to cover virtually any contingency. The extra cost this entails may be more than made up by the cost savings from reduced buys of the far more expensive high-tech spare parts. In addition, buying extra stockpiles of cheaper components may free up more test time on automated test equipment, especially one like IFTE, which will be able to test thousands of LRUs of widely ranging unit costs. Replacing demand for repair by relying on a stock buyout policy for these cheap components will reduce the overall demand for test equipment, thus further increasing possible savings. For some items, fast and responsive support simply is not the best alternative compared to simply buying more spares.

Supporting Future High Technology

The ultimate goal for the Army should be to eliminate altogether the need for fast and responsive support of the type described above. This may be achievable with future weapon systems. The type of support system argued for here was intended to support already fielded high-tech systems that are afflicted with low reliability, high removal rates, and expensive demands for support. The Army's goal, then, should not be to build more effective support systems for troublesome high-tech weapons, but to build more effective and reliable weapon systems in the first place.

To do so is no simple matter. It is not simply a case of specifying contracts better, or writing better warranties, let alone of simply "holding contractors' feet to the fire." The problem of expensive support and low reliability is endemic in the way the Army (and all users of high technology) design, build, and field these complicated new weapons. High technology is not intrinsically unreliable; in fact, as anyone who owns a modern TV versus a 20-year old model can attest, high technology is increasingly more reliable. The problem is not burnt-out circuits, but rather the complexity and density of demands put on the systems. In other words, the increasing capacity of high-tech systems pushes developers to load ever more sophisticated performance char-

acteristics into them. But these highly complex systems, which may work quite well in the laboratory, face all kinds of problems when introduced to the mud, grime, and chaos of real-world settings, including conditions (like jungle humidity and desert sand) that the engineers never fully considered in their laboratories.

Much of weapon system unreliability, then, is a matter of the weapon system adjusting performance in a very demanding environment. Once these problems are understood, they can be fixed and reliability can be greatly increased. The obvious problem, of course, is that doing so after the weapon system has been fully fielded in the hundreds or thousands can be both expensive and time-consuming. There may be better ways of achieving the same end.

The best way may be through "maturational development," a type of production/fielding concept developed at RAND. It anticipates the problems of new weapon system reliability when first fielded and attempts to build a better process that will achieve the desired high reliability at the least cost. The key is a combination of a low initial rate of production, intensive operation of these early production models, a rigorous and pervasive data collection effort to identify as early as possible reliability problems, and a feedback loop to the design and production engineers to incorporate findings from the field into the follow-on, and much larger, lots of production. This type of "preemptive retrofit" has a high probability of increasing overall reliability and, since it is built into the systems on the production line, can do so at much lower costs than the normal retrofitting process.[3]

While such a process will not eliminate all sources of high removal rates, especially those caused by the uncertainties of war, it will move the Army a long way toward building a weapon system that can virtually take care of itself—one that can fight with few removals and, thus, with little or no need for the large and cumbersome supporting force of mechanics, test equipment, transportation resources, or even support innovations like SRAs.

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[3]Fore more detail on the concept of "maturational development," see J. R. Gebman, D. W. McIver, and H. L. Shulman, *A New View of Weapon System Reliability and Maintainability*, RAND, R-3604-AF, January 1989.

FIELD TESTING OF NEW SUPPORT CONCEPTS

The Arroyo Center recognizes the need to move beyond conceptual analysis and to test how these ideas for more responsive support structures would work in the field. Our ongoing work has included studying the impact of alternative support structures and enhanced information management at a high-usage base like Fort Rucker, the Army's helicopter pilot training base.

The high payoffs from a responsive support structure as shown in a variety of Arroyo Center analyses point the way to the future for the Army. Much work needs to be done beyond modeling in computers, however. The biggest task of all is to demonstrate feasibility, that is, to identify what modifications to existing systems (data systems, management systems, policies and procedures for supply and repair, etc.) need to be made to make these systems work in real-world settings. The Army is currently pursuing tests to demonstrate both the value and practicability of such new support concepts, and the Arroyo Center will assist the Army in every way it can.

Assuming problems of feasibility are solved, the Army may find there are no insuperable obstacles to building more responsive support structures. This is the Army's great opportunity as it faces a world changing radically after nearly a half century of relative stability in the threat environment. RAND research has shown that adopting these new responsive support structures can not only yield greater weapon system availability than current systems provide, and do so at less cost, but they show gains to the Army in robustness and versatility that will help it meet the challenges facing it in this new era.

Appendix A

COST ELEMENTS OF ALTERNATIVE SUPPORT STRUCTURES

This appendix describes the development of the cost estimates found in the body of the report. We have used the most recent cost data available from Army organizations and the Martin Marietta Corporation. All costs are expressed in FY 1988 dollars and represent a 20-year life-cycle cost for the various personnel, equipment, and facilities.[1]

SRA SUPPORT

Table A.1 summarizes the elements used in estimating the cost of the TADS/PNVS SRA alternative.

Table A.1

TADS/PNVS SRA Test Set Cost ($ thousands)

Equipment	
Initial procurement	3,000
Operations and support (20-year life cycle)	700
Facility	
Initial refurbishment	10
Annual operations (20-year life cycle)	400
Four operators (20-year life cycle)	7,200
Total 20-year life cycle	11,310

[1]The 20-year life-cycle costs are computed by multiplying annual costs by a factor of 10 and adding the one-time nonrecurring costs. The factor of 10 assumes a discount rate of 7.75 percent. This factor is chosen primarily for analytical convenience. However, the cost multiplier is not very sensitive to the rate; for example, using a discount rate of 10 percent results in a multiplier of approximately 9.36.

The intermediate- and depot-level maintenance of the TADS/PNVS and other high-tech components on the Apache is currently accomplished by contractor personnel at contractor-operated facilities. The Army pays for this support through annual, level-of-effort contracts, although they have procured and own most of the equipment used by the contractors.

In our cost analysis, we have estimated costs for intermediate- and depot-support equipment over and above what currently exists or may exist in the future. We assume the existing Army-owned SRA equipment would be used in the CONUS to support training operations in wartime. We also assume that depot maintenance will continue to be provided by contractors. If existing SRA equipment is "surplus" for supporting CONUS-based training operations and if the Army's DESCOM does establish an organic depot capability, our costs may be overestimated by including costs that can be considered "sunk."

We cost the TADS/PNVS SRAs on the basis of an "equipment set." That is, we generate costs for facility refurbishment and annual operations assuming that there will be a single set of equipment in the facility. Obviously, some facilities will contain multiple sets of equipment. The cost differential in such cases should be minor since the facility costs are only a small portion of the total costs.

Facility Renovation and Annual Operations

We assume that facilities would be leased, mirroring the current mode of operations for CONUS and European SRAs. Each SRA set requires approximately 3000 to 4000 square feet of floor space. The facility needs special provisions, such as tile floors, 400 Hz power supply, and air conditioning. The actual cost to refurbish and lease a building is dependent on what provisions exist. As an example, Martin Marietta recently refurbished a building at Fort Rucker at a cost of less than $10,000, which included installation of a tile floor, extra lighting, air conditioning, and some concrete slabs and walkways.

The Apache TADS/PNVS Program Manager office provided an estimate of refurbishment cost of $25 per square foot (this factor matches the Martin cost at the 4000 square feet Fort Rucker facility). We assume that each SRA set requires 4000 square feet of floor space and that refurbishment cost is $25 per square foot. The total one-

time cost of setting up a facility for an SRA set is estimated at $10,000.

Annual leasing costs for a building are dependent on location, size, and provisions. Current Martin estimates for building leases are $1000 to $5000 per month. For example, the facility at Fort Hood costs $3500 per month, including utilities. We estimate the annual cost of facility leasing and utilities as $40,000; the 20-year life-cycle cost estimate is $400,000.

Equipment

Equipment costs include the initial procurement of the TADS/PNVS test sets, common test equipment such as oscilloscopes, test meters, etc., and the initial wiring and connections. Martin provided an estimate of $1.75 to $2.0 million per SRA set plus approximately $1 million for a hot mockup. Connection cost is approximately $50,000. Current Martin leasing costs for the common test equipment are $6000 per month. We use a factor of $3.0 million per SRA set (including initial connections) plus $70,000 per year for leasing the common test equipment. The resulting 20-year life-cycle cost estimate is $3.7 million per SRA set.

Personnel

There are two issues involved with estimating the personnel costs associated with operating the SRAs—the number of personnel required and the average annual cost per person. Our SRA alternatives assume that contractor personnel would operate the SRAs and perform the required maintenance. Based on information from Martin Marietta and the TADS/PNVS Program Office, we estimate a cost of approximately $85 per hour for these personnel. This rate is fully burdened, including all indirect, overhead, and administrative costs. The $85 per hour rate translates to a cost of approximately $180,000 per year for each repair person or a 20-year life-cycle cost of $1.8 million per person.[2]

The more difficult question is the number of personnel required to support wartime operations. A detailed analysis of personnel re-

[2]Using contractor personnel eliminates the need to estimate costs for initial and replacement training and personnel equipment. The training costs are wrapped into the hourly rate.

quirements would include expected workloads, availability factors, productivity factors, and desired turnaround times for the repair facility. Such analyses are often performed using simulation models of the repair process. Our initial estimates preclude such a detailed analysis and are based on a number of simplifying assumptions.

We first estimate the workload for each day of conflict based on the expected number of sorties, removal rates, and average repair times. The number of sorties is based on the daily fleet size, taking into account anticipated attrition, average sortie rates, and an assumed achievement of approximately 85 percent of planned sorties. The removal rates and repair times are based on current peacetime data. The above process leads to a workload of approximately 156 man-hours on the most demanding day of the war. Using this "expected" workload and a VTMR of 3, a 95 percent confidence interval would have an upper bound of almost 200 hours.

Martin uses a productivity factor of 160 hours per man per month for their current peacetime operations. This factor translates to about seven hours per day (using 4.3 weeks per month and five working days per week). In wartime, one could expect this daily productivity rate to increase as personnel work longer days. As an initial estimate of personnel requirements, we assume a daily productivity of eight hours and an average daily workload of 160 hours. This translates to approximately 20 people required for SRA repair functions (noting that indirect labor is included in the hourly labor cost).

Our modeling process suggests that five sets of SRA repair equipment are required. We therefore use a factor of four repair personnel per SRA equipment set. With the $1.8 million life-cycle cost per person, the resulting personnel cost per SRA set is $7.2 million for 20 years.

Total Costs: TADS/PNVS and Extended SRAs

Total cost for supporting a TADS/PNVS SRA for the Apaches in two corps is thus estimated at $57 million. No comparable data exist for costing an extended SRA (including repairs of IHADSS LRUs, FCC,[3] and the HARS). We estimate that the additional workload for these LRUs would be approximately one-quarter of that for the TADS/PNVS and increase the cost of the extended SRA proportion-

[3]A Test Program Set was fielded for the FCC in September 1990, after completion of this analysis.

ately. This would add an increment of $15 million to the cost of SRA support, for a total extended SRA cost of $72 million for life-cycle support of these Apaches.

DEPOT OPERATION

Costs for equipping and operating depot repair are estimated at $44 million over a 20-year life cycle for two corps of Apaches. This estimate is generated from an AMSAA study that costed depot repair of the TADS/PNVS.[4]

The AMSAA study calculated depot support costs for an Apache fleet of 675 aircraft; the study prorates those figures to support the 306 aircraft in two corps, yielding costs for test equipment of $16 million. It is assumed here that equal direct manpower is needed to handle the workload; fully burdened manpower in the depot is estimated in the AMSAA study at approximately one-half that in a contractor-run SRA. Manpower costs would then total $18 million.

Depot operation for the other critical items has not been analyzed; we assume again the cost is proportional, and calculate life-cycle costs for supporting these items at around $10 million. Total depot set-up and operation costs come to $44 million.

EETF UPGRADE

The only ongoing major upgrade to the EETF is Engineering Change Proposal ECP–185(R)2, a core computer upgrade costing $25 million and applying to the 22 EETFs, as well as another 14 floor-mounted ATE systems. The full extent of EETF performance improvement this ECP will yield cannot be predicted at this time. Our analysis assumed major improvements in EETF capability: 50 percent reduction in NRTS; 50 percent increase in EETF fully-mission-capable availability; and a 25 percent reduction in unit under test (UUT) time on the test equipment. No exact estimate can be made as to how much such improvements would cost. For purposes of illustration, we assumed a total cost of $25 million to upgrade the EETFs, which would, as assumed in this study, support over 300 Apaches in combat. This is only an estimate, of course; if EETF

[4]U.S. Army Materiel Systems Analysis Activity, *Independent Cost Assessment of Depot Maintenance Alternatives for the Target Acquisition Designation Sight/Pilot Night Vision Sensor (TADS/PNVS) of the AH-64A Apache Helicopter,* April 1988.

improvements could be made at lower cost, that would marginally increase the attractiveness of the Improved EETF and Enhanced Depot alternatives, at least in the base case.

ASSURED TRANSPORTATION SYSTEMS

Theater Transportation

Assured transportation in the theater could be achieved through a variety of means. Trucks, rotary aircraft, and fixed-wing aircraft are all possibilities. Compared to most of the payloads the Army must transport, like ammunition, the size of high-technology payloads is trivial. On average, the total size of that payload for two corps of Apaches is about 4000 lb and 400 cubic feet a day. This might double in times of intense operations. Such volumes are trivial by Army standards; in fact, the entire load could be carried in a single flight of many types of fixed-wing or rotary-wing aircraft.

To cost a theater transportation system, we used as a representative aircraft the Shorts 330/C-23A Sherpa, with a payload of 3175 kg, a carrying volume of 35.7 cubic meters, and a range of 362 km.[5] One such aircraft would suffice to move Apache LRUs. It is assumed that the aircraft needed for this mission would use existing support structures and personnel as a base, and that operation and support costs and those for personnel could be costed on the margin.[6]

Costs of supporting a Sherpa for a 20-year life cycle include:[7]

$5.0 million for aircraft

$5.5 million for operating and support costs

$10.3 million for personnel

[5]"Heavy Turboprop Aircraft," *Aircraft Forecast: Military and Civil,* Forecast Associates, Inc., 1987.

[6]This is the marginal cost to add sufficient transportation for high-tech Apache components onto an existing responsive distribution system. That fleet may, for example, be the European Distribution System. If that proves infeasible, the Army may benefit from developing its own theater distribution system to handle an increasing workload from its high-technology weapon systems, such as the M-1, M-2/3 and AH-64 now, and the Light Helicopter in the future.

[7]The acquisition cost is based on a personal communication with the Shorts Brothers U.S. representative; operating and support costs and personnel costs are based on information from the U.S. Air Force (Europe) European Distribution System Program Office.

If the SRAs or the airports of embarkation are located farther forward in the communications zone, less expensive rotary-wing transportation could be used. UH-60 Blackhawk helicopters are found in assault companies and logistical support units of the corp CABs; access to a Blackhawk for transporting high-tech LRUs might be made assured at no additional dollar cost to the support structure. Even if new aircraft had to be added to the fleet for this purpose, the cost of purchasing and operating an additional UH-60 (which could handle the payload of two corps) is estimated at under $12 million.[8]

Intertheater and Intra-CONUS Transportation

Costs for assured intertheater and intra-CONUS transportation are not estimated in this study. It is possible that airframes may be made available from the Civil Reserve Air Fleet (CRAF) to serve both for intertheater and intra-CONUS travel. The greatest demand on CRAF capability is for over-the-ocean wide-body craft. Although these high-technology components would also require over-the-ocean capability, their small weight and volume allow them to be carried by any type of overseas aircraft, including narrow body, of which many exist in the CRAF; conceivably, these items could be carried in the spare cargo areas of wide-body aircraft leaving for CONUS every day from the theater. In CONUS itself, delivery to the depot facility may similarly be carried out by narrow-body CRAF aircraft.

As the CRAF is a nominally "free" source of transportation (the military pays for structural modifications not necessary here, navigational aids, and contracts peacetime usage of commercial carriers), there would be small or no cost for this portion of the transportation system if a requirement for the Military Air Command is generated to use its CRAF capability to rapidly transport critical high-technology components.

MANAGEMENT INFORMATION SYSTEM

RAND, along with the Army Materiel Command (AMC) and the Training and Doctrine Command (TRADOC), is currently investigating the feasibility and cost of developing and implementing an Army-wide management information structure. Such a system, known as RBMS, would provide accurate and up-to-date information on asset

[8]R-3673-A, pp. 57-61; this is a complete twenty-year life-cycle cost.

location and needs of units for components to achieve availability goals. It could operate in the depot (or other repair location) to guide workshop inductions, and in the theater to determine final destination for shipping.[9] Costs for such a system are difficult to estimate at present, although based on experience with management information systems with similar functions, development costs may reach $5 million per year for development. The operating and support costs are likely to be around $2 million per year.[10]

Any such system would probably be implemented to handle all corps and all major weapon systems, especially those dependent on high technology. The marginal cost of such a system to support two corps worth of Apaches may be quite small, then, possibly on the order of $1–$2 million over a 20-year life cycle. This assumes, of course, that the system covers the entire Army; clearly, if nothing like RBMS exists, the enhanced depot option may become unsupportable.

STOCK

Dyna-METRIC allows the calculation of the amount of stock needed to buy out pipelines in order to achieve an operational goal at minimum cost. Stock costs in this study are derived from Dyna-METRIC results, with inputs coming from the Army Master Data File (AMDF) for LRU unit cost and the Unscheduled Maintenance Sample Data Collection for LRU removal rates and variability.

This, however gives only a snapshot of stock costs, which we believe are unavoidably underestimated in this study. Reasonable cost estimates are usually based on a full life cycle, assumed here to be 20 years. Stock has life-cycle costs as well. The amount and cost of stock bought initially for a weapon system will not suffice throughout the life cycle for a variety of reasons: condemnation, modifications of existing stock, recalculation of pipeline needs, and the like. Some research suggests[11] that these costs may be quite large, conceivably

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[9]See App. B.

[10]This cost is for the Air Force Weapon System Management Information System (WSMIS), which provides weekly assessments to Air Force wing commanders and is reported to the Air Force unit readiness reporting system. For information on WSMIS, see *WSMIS Sustainability Assessment Module (SAM), Functional Description (Version 8.0)*, Dynamics Research Corporation, Andover, Massachusetts.

[11]See for example, K. J. Hoffmayer, F. W. Finnegan, and W. H. Rogers, *Estimating USAF Aircraft Recoverable Spares Investment*, RAND, R-2552-PAE, August 1980.

double the amount shown in this study. However, the actual impact of life-cycle effects is not well understood and demands further study. No attempt at a life-cycle costing of stock is included in this study; were some estimate used, it should be noted that the result would be to increase the relative cost-effectiveness of the responsive support alternatives, which emphasize repair and transportation over stock.

Appendix B

ISSUES IN DEVELOPING RESPONSIVE SUPPORT STRUCTURES

Two issues in developing responsive support structures demand particular attention, for they would require changes in Army support structure, doctrine, philosophy and even culture. To build a responsive support system, the Army would need to create means for assured distribution and priority repair. The evidence in this report indicates that the costs of such distribution systems are most likely justified.

ASSURED TRANSPORTATION

The transportation system for high-tech, high-cost LRUs must be fast and flexible, and robust and assured in the face of wartime unit movement, damage to assets, and confusion. In spite of the universal shortage of transportation for high-tonnage items, the LRUs are so critical that their shortage would suggest an unacceptably high system cost. The combat value gained from specialized support structures for these critical items means that assured transportation for them must be provided even though this may be at the expense of overall transportation efficiency.

Speed will require a special system that minimizes waiting for internodal transshipment. Flexibility for a varying workload will require operating with excess capacity much of the time so that peak loads can be carried when they occur. The times of peak loads will generally be when the transportation system is most critical for weapon system availability.

An assured transportation system would be made up of three discrete parts. The first part, A, is in-theater transportation. This part consists of what might be called a "bus system." The vehicles in this system routinely travel to all locations where LRUs requiring maintenance originate, pick them up, and deliver them to one of several types of local maintenance facilities for evaluation and/or repair. If

repaired locally, they are again put on the "bus" for delivery to the point of need. If the repair exceeds the local abilities, the LRUs are delivered by the bus to a designated point of embarkation.

The second part of the transport system, B, consists of air transport from the port of embarkation on the theater continent to a point of debarkation in the United States, and return. Daily flights would ensure that bad LRUs could arrive in the United States in 24 hours or less, and that repaired LRUs would return to the theater port in the same time.

The third part of the system, C, would take defective LRUs from the port of debarkation to an appropriate depot, and take repaired LRUs back to the port for return to the theater. This system would be very much like a domestic Federal Express system, but with far fewer nodes. It would operate between the designated ports in the United States and the appropriate depots. It would be an air system, and would again assure 24-hour delivery service between the ports and depots.

Each portion of this transport system requires equipment with special characteristics. It must be reliable, have adequate backup for contingencies, be easily operated, simple, and not amenable to preemption for other purposes.

Portions B and C of this system are the simplest, both from a conceptual point of view and from the view of implementation. Portion C, for example, involves only domestic movement of LRUs to and from depots and ports. As mentioned above, it is a kind of mini-Federal Express system with relatively few nodes. There are several simple possibilities for this portion of the system. First, it may be possible to use existing commercial services, such as Federal Express, Purolator, or others. Or the U.S. Postal Service, which operates an overnight system, may be a possibility. If control of the system must be in the hands of the military, perhaps some of these same domestic commercial carriers are part of CRAF, which may be a means of solving the problem. If none of the above is satisfactory, the purchase of the right number of dedicated aircraft for this service would solve the problem.

Portion B appears similarly simple. During war, there will undoubtedly be a large number of daily military flights between ports in the United States and those in the theater. The most obvious step is to determine whether there would be space on these flights for the LRUs, and if so, whether the LRUs would be certain not to be bumped

from the flights by other materiel. If the use of existing flights is not satisfactory, then a dedicated daily flight system could be set up that would be based on either military aircraft or CRAF (the light weight and small volume of these components make narrow-body aircraft a feasible transportation alternative, and such transport would be needed only in wartime).

Portion A presents more difficulties. The analysis here is complicated by the fact that the transportation system must operate in-theater, where a maximum amount of movement of both troops and materiel is taking place, and where a high order of confusion may exist. In addition, surface transport may be complicated by clogged or damaged roads, frequent military checkpoints, or even enemy fire. Further, there may well be several "legs" to the transportation journey, with frequent off- and on-loading of trucks. This complexity requires that the transport system be responsive and rapid in the face of these various kinds of adversity, so that LRUs are not unnecessarily delayed in transport. One solution is a dedicated, or at least assured, transportation network made up of fixed-wing or rotary aircraft that could be supported by existing support structures in the theater. One example of this kind of system, based on the Shorts Brothers C-23A Sherpa, is estimated to cost in the neighborhood of $21 million; this cost is broken down in App. A. Alternatively, division CABs could provide on a rotating basis UH-60 Blackhawk helicopters for an intratheater "Federal Express" pool.

MANAGEMENT INFORMATION SYSTEM FOR REPAIR AND DISTRIBUTION[1]

A responsive support structure necessitates development and implementation of tools that will facilitate the most effective repair and distribution of LRUs and SRUs. RAND, along with AMC and TRADOC, is investigating the feasibility and cost of developing and implementing an Army-wide management information structure. This system, known as the Readiness-Based Maintenance System (RBMS), is a decision support system intended to assist logisticians, including Theater Army Materiel Management Centers (MMCs) and

[1]This section is adapted from Robert S. Tripp, Morton B. Berman, and Christopher L. Tsai, *The Concept of Operations for a U.S. Army Combat-Oriented Logistics Execution System with VISION (Visibility of Support Options)*, RAND, R-3702-A, March 1990. The name of the system was changed from VISION to RBMS.

Major Subordinate Command (MSC) inventory managers (IMs), in managing logistics resources.

There are four key components in the design of RBMS. The first is a measure of merit, which will be weapon system availability. The second component is a short-term weapon system operating tempo requirement for each combat unit, used to project expected wartime and peacetime demands for individual components. Third, the system uses the "current" data on the availability of resources and their status to develop the appropriate execution actions at each echelon. The fourth component is a model for prioritizing repairs and distribution. The DRIVE (Distribution and Repair in Variable Environments) model[2] contains many of the features needed to operate RBMS.

The outputs of RBMS are designed to provide the capability to:

- Determine the priority of repair actions, given existing resources, that maximize weapon system peacetime and wartime availability. This capability will allow resources used to repair a group of items to be expended in the order that yields the highest weapon system wartime and peacetime availability payoff.
- Guide distribution decisions such that items are shipped to locations where they achieve the greatest improvement in reaching weapon systems availability objectives.
- Project resources needed to meet repair workloads on a quarterly basis. This capability will include the ability to show the effects of moving or reallocating budgets and resources for one group of items to others on wartime and peacetime weapon system capability.
- Develop yearly budgets for individual repair items. These tools will show the effects of funding alternatives on wartime and peacetime weapon system availability.

If RBMS is developed, several new and additional kinds of logistics data will be necessary. The new logistics data include asset visibility, scenarios, item indicative data (removal rates, order and ship times, etc.), interchangeable and substitutability groupings, and indenture relationships.

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[2]The work to develop DRIVE has been sponsored by HQ USAF and HQ Air Force Logistics Command (AFLC) under a RAND Project AIR FORCE study. The algorithm has been developed and tested at the Ogden Air Logistics Center with the active participation of Air Force personnel.

The RBMS system is likely to pay wartime dividends in terms of more effective repair and distribution of expensive LRUs critical to weapon system performance. As outlined in the main body of this analysis, implementing RBMS, as part of an overall strategy of developing responsive support structures, could yield substantial savings in support costs while offering flexibility and robustness to handle the uncertainties of warfare.

Appendix C

INPUT PARAMETERS FOR HIGH-TECHNOLOGY APACHE LRUs USED IN THE MODELING

Tables C.1 and C.2 present information on LRU cost, removal rates, and repair characteristics for all components modeled in this study.

Table C.1

Cost and Removal Rate Information

LRU	Work Unit Code	Removal Rate (per hour)	VTMR	Unit Cost ($)
Stabilator controller	02D02	.00112	1.00	7,252
Torque indicator	08A03	.00028	1.00	5,558
Signal data converter	08C01	.00052	0.86	12,639
Engine out warning	08C02	.00042	1.00	2,639
Digital display indicator	08D09	.00083	1.00	30,182
Battery charger	09D02	.00112	1.00	4,343
Dimmer controller	09E02G	.00098	1.00	10,215
Audio junction box	19A04	.00026	1.37	4,383
HARS	19G	.00314	1.26	62,400
DASE	19M01	.00105	0.73	21,032
Fire control computer	31A	.00209	1.35	16,789
Fire control panel	31B01	.00157	1.59	7,482
MRTU type I	31B02D	.00039	0.75	37,358
MRTU type III	31B03	.00052	1.40	42,446
Omnidirectional sensor	31C01	.00157	0.83	15,630
Air data processor	31C02	.00085	1.53	23,085
Remote electronics	32A	.00078	3.41	9,754
RH launcher	32B01	.00085	1.12	10,793
TADS electronic unit	33A	.00549	1.61	89,069
TADS electronic amp	33A01	.00346	1.94	16,860
TADS power supply	33A02	.00144	2.32	44,108
Laser electronic unit	33B	.00052	1.29	44,122
Bore sight assembly	33C02	.00059	0.99	21,875
TADS turret assembly	33C	.00170	1.03	150,082
Night sensor assembly	33C06	.00353	1.66	164,767
Day sensor assembly	33C07	.00085	1.56	150,082

Table C.1—continued

LRU	Work Unit Code	Removal Rate (per hour)	VTMR	Unit Cost ($)
TV sensor assembly	33C08	.00111	2.78	39,018
Rate gyro assembly	33C08A	.00039	1.29	5,932
Laser transceiver unit	33C09	.00131	1.52	63,134
Laser tracker receiver	33C10	.00052	0.58	28,647
Night sensor shroud	33C11	.00046	1.89	34,566
Optical relay column	33C14	.00085	1.16	87,141
Control panel assembly	33C15	.00052	1.29	23,100
Left hand grip	33D03	.00013	0.94	1,804
Right hand grip	33D04	.00059	1.02	3,025
IVD electronics assembly	33F	.00176	1.78	31,086
PNVS turret assembly	34A02	.00359	2.55	161,480
Shroud assembly	34C	.00196	1.68	36,204
Azimuth drive assembly	34D	.00078	2.18	15,272
PNVS electronic unit	34E	.00017	3.21	41,003
PNVS electronic amp	34F	.00065	2.25	7,900
Turret control box	35B06	.00111	1.82	24,964
Gun control box	35B07	.00046	0.94	7,089
Symbol generator	38	.00144	1.13	14,581
DEU assembly	39B01	.00118	1.14	12,577
SEU assembly	39C01	.00170	3.16	35,401
Display adjust panel	39E	.00098	1.12	5,558
Sensor survey unit	39F	.00366	7.08	6,217
Helmet display unit	39G	.00771	4.25	8,593

Table C.2

Repair Characteristics of LRUS Modeled

LRU	WUC	EETF Repair Time (hr)	EETF NRTS	SRA Repair Time (hr)	SRA NRTS
Stabilator controller	02D02	1.2	0.05	—	—
Torque indicator	08A03	1.9	0.33	—	—
Signal data converter	08C01	1.7	0.20	—	—
Engine out warning	08C02	0.5	1.0	—	—
Digital display indicator	08D09	0.7	0.0	—	—
Battery charger	09D02	1.7	0.77	—	—
Dimmer controller	09E02G	3.1	1.0	—	—
Audio junction box	19A04	1.2	0.0	—	—
HARS	19G	—	—	—	—
DASE	19M01	4.6	1.0	—	—
Fire control computer	31A	—	—	—	—
MRTU type I	31B02D	3.6	0.38	—	—
MRTU type III	31B03	3.8	0.0	—	—
Omnidirectional sensor	31C01	—	—	—	—
Air data processor	31C02	2.6	0.60	—	—
Remote electronics	32A	2.4	0.0	—	—
RH launcher	32B01	5.3	0.0	—	—
TADS electronic unit	33A	4.6	0.18	1.9	0.0
TADS electronic amp	33A01	—	—	1.7	0.0
TADS power supply	33A02	2.6	0.39	2.9	0.0
Laser electronic unit	33B	3.6	0.40	1.9	0.06
Boresight assembly	33C02	—	—	1.2	0.11
Turret assembly	33C	2.4	0.0	2.6	0.0
Night sensor assembly	33C06	6.0	0.64	3.4	0.04
Day sensor assembly	33C07	4.3	0.12	1.9	0.0
TV sensor assembly	33C08	2.4	0.0	1.2	0.58
Rate gyro assembly	33C08A	—	—	1.2	0.0
Laser transceiver unit	33C09	2.6	0.40	1.0	0.39
Laser tracker receiver	33C10	—	—	1.0	0.41
Night sensor shroud	33C11	0.5	0.67	—	—
Optical relay column	33C14	—	—	1.9	0.0
Control panel assembly	33C15	0.7	1.0	1.2	0.0
Left hand grip	33D03	1.4	0.33	1.2	0.0
Right hand grip	33D04	1.4	0.16	1.2	0.0
IVD electronics assembly	33F	8.4	0.48	2.4	0.0
PNVS turret assembly	34A02	8.2	0.24	3.8	0.03
Shroud assembly	34C	2.4	0.0	—	—
Azimuth drive assembly	34D	3.4	0.14	1.9	0.0
PNVS electronic unit	34E	1.4	0.20	2.2	0.0
PNVS electronic amp	34F	—	—	1.7	0.0

Table C.2—continued

LRU	WUC	EETF Repair Time (hr)	EETF NRTS	SRA Repair Time (hr)	SRA NRTS
Turret control box	35B06	1.4	0.0	—	—
Gun control box	35B07	1.0	0.12	—	—
Symbol generator	38	6.0	0.40	—	—
DEU assembly	39B01	4.3	0.0	—	—
SEU assembly	39C01	3.6	0.17	—	—
Display adjust panel	39E	4.1	0.50	—	—
Sensor survey unit	39F	—	—	—	—
Helmet display unit	39G	—	—	—	—

The tables were generated from a variety of sources. Removal rates and variance-to-mean ratios are from the AH-64 Unscheduled Maintenance Sample Data Collection. Unit costs are from the Army Master Data File. Repair times and NRTS rates at the EETF are from the EETF RAM/LOG data collection effort. Repair times and NRTS rates for TADS/PNVS LRUs at the TADS/PNVS SRA are from the Martin Marietta Aerospace Corporation data collection effort.

Not all EETF-reparable LRUs are individually modeled in this study. The EETF currently tests 78 LRUs. Several of the TPSs have been fielded since the conclusion of data gathering for this study; in other cases, there was little field information to make reliable estimates of run times or NRTS rates. To reflect probable workloads on the EETF in wartime, we estimated in an aggregate fashion the likely size of the additional workload these other LRUs would demand and captured their impact by decrimenting the EETF time available for testing of the LRUs we did model.